INDEX FOR: POLYMER

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Memo	Test to determine relative resistance of several insulating structures to gunfire	Sweeney, JO	Insulator Dept. GE Baltimore, MD	3/26/1963
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IEEE CP 31 CP 65-663	FIELD SERVICE TRIALS OF POLYMER INSULATORS FOR HIGH VOLTAGE TRANSMISSION LINES	Vose, Fred C	GE-Insulator Dept Baltimore, MD	4/6/1965
Paper	USE OF FIBERGLASS IN CONSTRUCTION OF TRANSMISSION LINES	Jerome, FD		10/5/1966
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TR LK-864	COMPOSITION OF LOW VOLTAGE POLYMERIC INSULATORS MARKETED BY OUR COMPETITORS FOR INDOOR USE	Nichols, G.	General Electric Blatimore, MD	2/2/1968

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Paper	POLYMER HIGH VOLTAGE INSULATORS FOR OUTDOOR USE	Wheeler, Edw S.	GE-Insulator Dept Baltimore, MD	5/10/1968
Listing	OUR FAMOUS FIRSTS IN THE FILED OF ELECTRICAL INSULATION		Insulator Dept Baltimore, MD	July 1968
68LK906	DEVELOPMENT OF ANTITRACKING GEPOL HIGH VOLTAGE INSULATORS	Vose, Fred C.	GE-Insulator Dept Baltimore, MD	Nov. 1968
11-1969	NGK RESIN INSULATORS		NGK Insulators Ltd	1969
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Pamphlet	HIGHEST LEAKAGE CURRENT IMPULSE AS CRITERION FOR THE INSULATION PERFORMANCE OF POLLUTED INSULATORS	Verma, M.P.	FGH Mannheim-Rheinau	
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Copy Cat. 302-69	UNITARY SUSPENSION INSULATOR		Joslyn Mfg & Supply Pinco Divn	1969
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Paper	CHARACTERISTICS OF FIBERGLASS AND POLYMER INSULATOR	Wheeler, Edw S.	GE Insulator Dept	April 1971
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Pamphlet	GEPOL INSULATORS: NEW LEVELS OF PERFORMANCE, ELECTRICALLY AND MECHANICALLY	Vose, Fred C	GE Insulator Dept Baltimore, MD	May 1971
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Draft	Minutes - WG ON TESTING & APPLICATION OF NON-CERAMIC INSULATORS	Karady, Dr. G.	IREQ Quebec, Canada	10/1/1975
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Letter	NON-CERAMIC INSULATORS W.G.	Kimoto, I.	NGK Ins. Ltd.	12/17/1975
EIX 75-12	POLYMERIC INSULATORS		NERAC	12/31/1975
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Listing	POLYMER INSULATORS (Adviterizers)		T&D	1976
Paper	MECHANICAL RATING OF NON-CERAMIC COMPOSITE LONGROD INSULATORS	Bauer, Ewald A	Rosenthal W. Germany	6/29/1976
Paper	A CONTRIBUTION REGARDING MECHANICAL RATING OF NON-CERAMIC COMPOSITE LONGROD INSULATORS with enclosures	Bauer, Ewald A.	Rosenthal	1/18/1977
Copy	OB-HI-LITE SUSPENSION INSULATORS	Menzel, Howard G.	OB	9/1/1976
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Excerpt	T&D INDUSTRY DEVELOPMENTS -- Test proves silicone okay for HVDC Insulators -- Synthetic insulators used on 735-kV line		Transmission & Distribution Magazine	Dec. 1977
Advertizement	RODURFLEX HTV - COMPOSITE LONGROD INSULATOR ACCORDING TO THE SYSTEM		Reliable Elec. Co.	

1796-63-8

Basic Text of Presentation on New Polymer Insulator for High Voltage Transmission Lines at Press Meeting on May 8, 1963 at Park Lane Hotel, New York City

Arthur E. Peltosalo, General Manager
Insulator Department
General Electric Company
Baltimore, Maryland

General Electric announces Phase 3 of its long range program to provide uniquely different insulation systems for high voltage electric power systems. Phase 3 is pilot production of fiber-glass polymer suspension insulators (Company trademark is GEPOL) in cooperation with electric utility systems who will make trial installations in 1963-64.

The initial phase of this research program was the development of the material and process for an experimental insulator model. The second phase involved limited field test installations, along with continued process development in perfecting the initial experimental models.

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From the very start of the high voltage electric power systems at the turn of the century, the wires carrying electric current have been insulated from poles and towers by means of porcelain insulators. For over 60 years there has been no fundamental change in the excellent qualities of porcelain insulators used to prevent the electric current from short circuiting to the supporting pole or tower and thus causing a blackout on that portion of the electric system. These insulators are of critical importance because if they fail, there are all the inconveniences of a blackout. Also, since hundreds of millions of insulators are used, they represent a significant investment to the electric utilities.

In the 1950's the General Electric Insulator Department in Baltimore (formerly the Locke Insulator Corporation which General Electric purchased in the 1920's) surveyed the many new materials which had been born during and after World War II to see if there wasn't a way to bring real changes to insulator materials. Several years of laboratory work convinced General Electric's scientists that a combination of fiber-glass and an epoxy polymer offered substantial advantages over porcelain. Porcelain is an excellent insulator, has a remarkably long life because of its inert qualities, uses very low-cost raw materials, and has a proven service history extending over at least 60 years. Nevertheless, there are disadvantages to porcelain in that

(1) it is relatively brittle, which means it is easily damaged in handling or by malicious rifle firing which plagues many electric utilities; (2) it is heavy and requires special handling when working at the tops of power line poles and towers (its weight also influences the strength needed in the pole itself); (3) it depends upon raw materials as they come out of the ground and as a result, it is difficult in the manufacturing process to compensate for the material variations; (4) longer lengths of suspension insulators are made of many small individual units which are joined by metal parts which are heavy, costly (much more so than porcelain), non-insulating, and offer the potential source of a separation failure; and (5) it requires very large and complex processing equipment which contributes to the basic cost of producing porcelain. General Electric's studies show that with production of fiber-glass polymer insulators approaching the quantity levels of porcelain there are good reasons to expect a significant cost savings to be obtained. During the Phase 3, however, General Electric GEPOL units will be priced substantially higher than equivalent porcelain insulators in order to partially recover the development costs.

Phase 3 was signaled when on May 1, 1963, General Electric opened its brand new all white clean-room concept pilot plant in Baltimore for the production of the GEPOL insulators.

Sufficient units will be made in 1963-64 to enable General Electric to continue its extensive laboratory tests and also to begin obtaining field test data in cooperation with electric utilities throughout the United States.

A jump has already been made on obtaining the vital field experience which is so important to electric systems which must be built to have essentially no outages. In 1959 in cooperation with Florida Power & Light Co., Baltimore Gas & Electric Co., and the New England Electric System, test installations were made at 69,000 volts and 115,000 volts. Continued monitoring of these installations has shown excellent results with no deterioration which is visible or has been when units have been brought back to the laboratory. It is also interesting to note those same type units have been operating for over one year at 500,000 volts at General Electric's Project EHV in Pittsfield, Mass. Everyone associated with the GEPOL project knows that even a four-year life is no assurance that the needed 20 to 40-year life will be obtained. General Electric scientists are presently unable to predict the ultimate life because they have been unable to determine any deterioration as yet after four years field service. The necessity of proving the life on as broad a sample basis as possible is why General Electric will cooperate with the electric utilities to be sure each has experience under their own system operating conditions.

General Electric's business managers are cautiously optimistic. They point out that with the completion of Phase 3 they will have expended over $250,000 on the project. They also know that full production will involve the expenditure of at least $1,000,000 more. However, General Electric, which believes it has a strong patent position, knows the stakes are high. There are some $16,000,000 of porcelain suspension insulators purchased in the United States every year. The opportunity to supply this market with a product is the profit lure that spurs General Electric on to continue this costly program until the answers to ultimate life and economies of construction are firmly established.

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NEWS BUREAU
GENERAL ELECTRIC
SCHENECTADY 5, N. Y.

R. B. Piorkowski

1796-63-6

FOR RELEASE AFTER 6:30 P.M., EDT, WEDNESDAY, MAY 8, 1963

NEW YORK, May 8 --- Development of electrical insulators made of synthetic materials which could save the nation's electric power companies millions of dollars within the next decade was announced here today by General Electric.

The development culminates nearly ten years of extensive research and development by the company in an attempt to provide an improved insulation system for high voltage transmission lines. The new GEPOL* insulators which have already been proven on transmission lines of three major electric utilities, are expected to be the forerunners of a complete line of insulators for tomorrow's extra high voltage transmission systems.

GEPOL insulators are made of a combination of fiber-glass and an epoxy polymer instead of porcelain which has been the insulating material used for more than 60 years.

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* Trademark of the General Electric Company

Simultaneous with this new development, Arthur E. Peltosalo, general manager of the company's Insulator Dept., Baltimore, Md., announced the opening of a new Polymer Pilot Shop and Laboratory for further research and the pilot production of more than 1,000 GEPOL insulators in cooperation with utilities who will make trial installations during 1963-64. One thousand of the new GEPOL insulators are the equivalent of 7,000 present-day porcelain units.

Peltosalo said that "with the completion of the new laboratory and the beginning of pilot production, the company has expended more than $250,000 on this project."

He stated further that full production of insulators, which is dependent on the continued success of the extensive field installation trials, would involve the additional expenditure of more than $1,000,000 by the company.

Peltosalo pointed out that the company has a strong patent position in a U.S. market where more than $16,000,000 worth of porcelain suspension insulators are purchased each year.

"The opportunity to supply this market with a quality product," Peltosalo said, "is the profit lure that spurs General Electric on to continue this costly program until the answers to ultimate life and economies of insulator construction are firmly established.

He pointed out that "General Electric studies indicate that when production of fiber-glass polymer insulators approach the quantity levels of porcelain, a significant cost savings can be obtained."

"However," he added, "during the pilot production phase of our long range program, General Electric GEPOL units will be priced substantially higher than equivalent porcelain insulators in order to partially recover the development costs."

Insulators are electrical devices that insulate and support transmission lines which carry electric current to industry and homes, and prevent the electric current from short circuiting to a supporting pole or tower to cause blackouts.

Test installations using the new fiber-glass polymer suspension insulator have been made at 69,000 volts and 115,000 volts for the past four years in cooperation with Florida Power and Light Co., the Baltimore Gas & Electric Co., and the New England Electric System.

In addition, a 500,000-volt test installation at General Electric's Project EHV in Pittsfield, Mass., was started in January, 1962.

Results of these field trials indicate no deterioration on any of the fiber-glass polymer insulators --- one reason why General Electric scientists are unable to predict the life-expectancy of the new insulators and why more field trials will take place within the next two years.

Since the new GEPOL insulators are made of synthetic materials, they can be closely controlled and are not subject to contamination by impurities associated with normal porcelain raw materials dug from the ground.

The new insulators weigh less than one-third that of porcelain insulators with a resultant reduced cost of transportation and handling. They feature both electrical and mechanical characteristics which far surpass present-day porcelain insulators.

GEPOL insulators have a far superior impact strength which will help eliminate the electric utility industry's major problem of breakage from handling and would aid in reduced outages caused by rifle fire and other accidental and malicious impacts during normal operation.

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R. B. Piorkowski

1796-63-7

(5/8/63)

FOR IMMEDIATE RELEASE

GENERAL ELECTRIC DEVELOPS NEW POLYMER INSULATOR; OPENS NEW POLYMER PILOT SHOP AND LABORATORY

Development of a new synthetic suspension insulator which could revolutionize transmission-line insulation, and the opening of a new Polymer Pilot Shop and Laboratory in Baltimore, Md., has been announced by General Electric's Insulator Department.

Called the new GEPOL* insulator, the fiber-glass polymer insulator is the culmination of nearly ten years of extensive research and development by General Electric scientists and engineers at its Beltimore laboratories.

The new GEPOL insulators, 70 per cent lighter than equivalent porcelain units and far superior in impact strength, are expected eventually to be the forerunners of a complete line of insulators for today's and tomorrow's extra high voltage transmission systems.

-more-

*Trademark of the General Electric Company

Arthur E. Peltosalo, department general manager, said opening of the $100,000 Polymer Pilot Shop and Laboratory is the beginning of the third phase of General Electric's long range program to provide improved insulation systems for high voltage electric power systems.

Peltosalo said plans include the pilot production of more than 1,000 fiber-glass polymer suspension insulators in cooperation with electric utilities who will make trial installations during the remainder of this year and in 1964.

The first phase of the company's program was the initial development of the material and process, along with the production of the first experimental model of the GEPOL insulator. The second phase involved continuous process development and limited field test installations.

Four field test installations were made since 1959; a 500 kv installation at General Electric's Project EHV, Pittsfield, Mass., a 115 kv installation at Baltimore Gas & Electric Co., and two 69 kv installations at Florida Power & Light Co. and New England Electric System.

Results thus far indicate no deterioration of any of the polymer suspension units on any of these test areas along with reports of perfect performance records.

The new units feature an extremely high mechanical impact strength which reduces breakage due to vandalism and during construction, and a high thermal shock resistance to reduce damage from power flashover.

The new GEPOL insulators are virtually puncture-proof and eliminate line drops from exploded caps. Their flexibility of design permits a wide range of strength requirements and greatly reduces the risk of insulator breakage due to hardware corrosion.

Design of the polymer insulators provides a very positive supporting structure without reliance on cemented joints and has an excellent R.I.V. performance. In addition to a promise of improved performance in contaminated atmospheres, the new GEPOL insulator minimizes the number of loose or flexible parts to be handled during construction of a transmission line.

Peltosalo said, "We estimate that the costs of going into full production would involve the additional expenditure of more than $1,000,000. This, of course, is dependent on the successful outcome of the extensive field trial installations now being planned."

He pointed out the company has spent more than a quarter of a million dollars since the inception of the project nearly ten years ago.

Peltosalo said the "company believes it has a strong patent position and knows the stakes are high in a U.S. market where $16 million of porcelain suspension insulators are purchased every year."

"The opportunity to supply this market with a product," he said, "is the profit lure that spurs General Electric on to continue this costly research and development program until the answers to ultimate life and economies of construction are firmly established."

General Electric studies indicate that with production of fiber-glass polymer insulators approaching the quantity levels of porcelain, there are good reasons to anticipate a significant cost savings.

Peltosalo said, "During the pilot production phase, however, General Electric GEPOL units will be priced substantially higher than equivalent porcelain units in order to partially recover the development costs."

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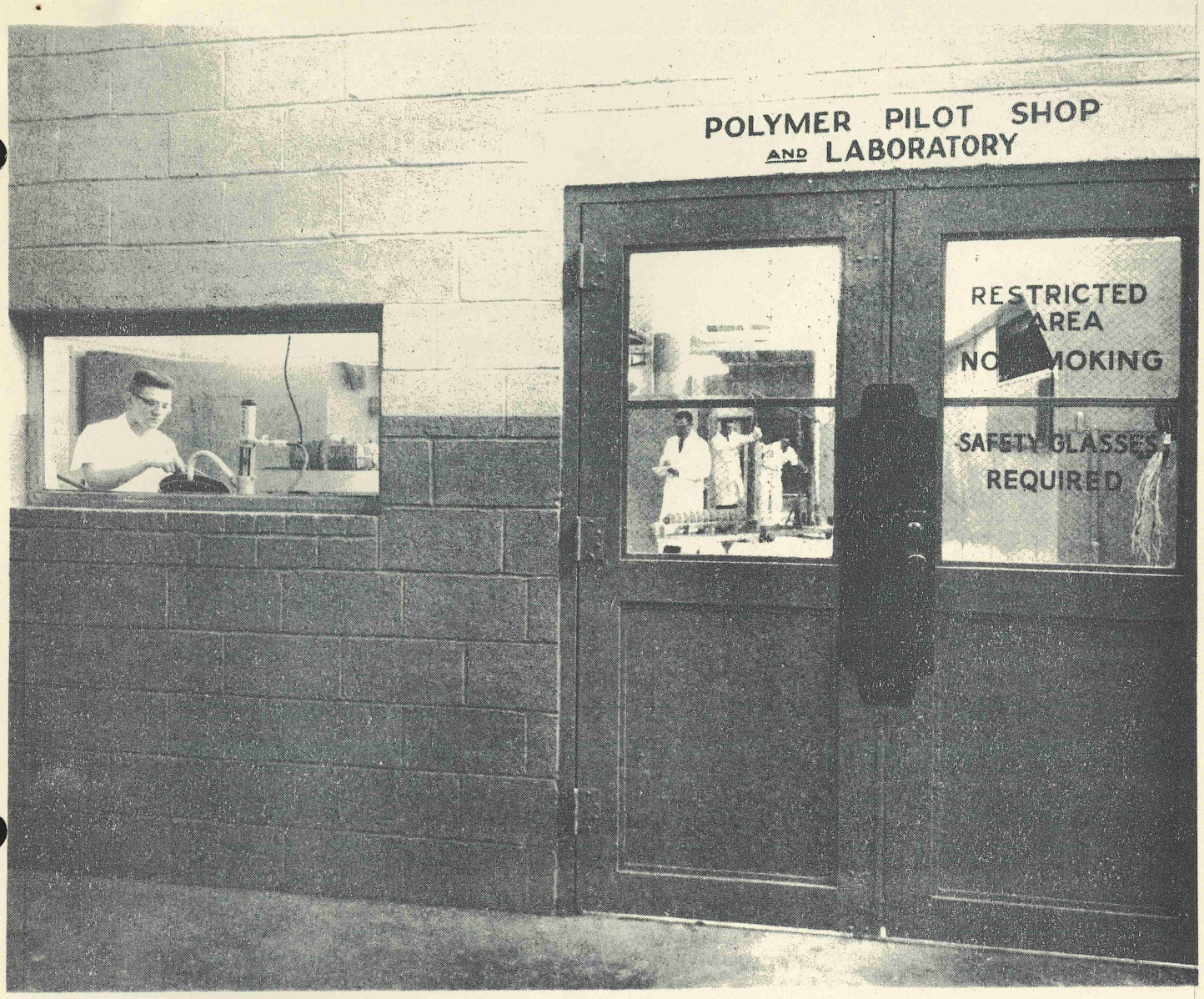

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1796-63-5A

(5/8/63)

FOR IMMEDIATE RELEASE

External view looking into General Electric's new $100,000 Polymer Pilot Shop and Laboratory shows clean-room type techniques which will be used in the pilot shop production of the more than 1,000 GEPOL* suspension insulators which will go to utilities who will make field trial installations the remainder of this year and during 1964.

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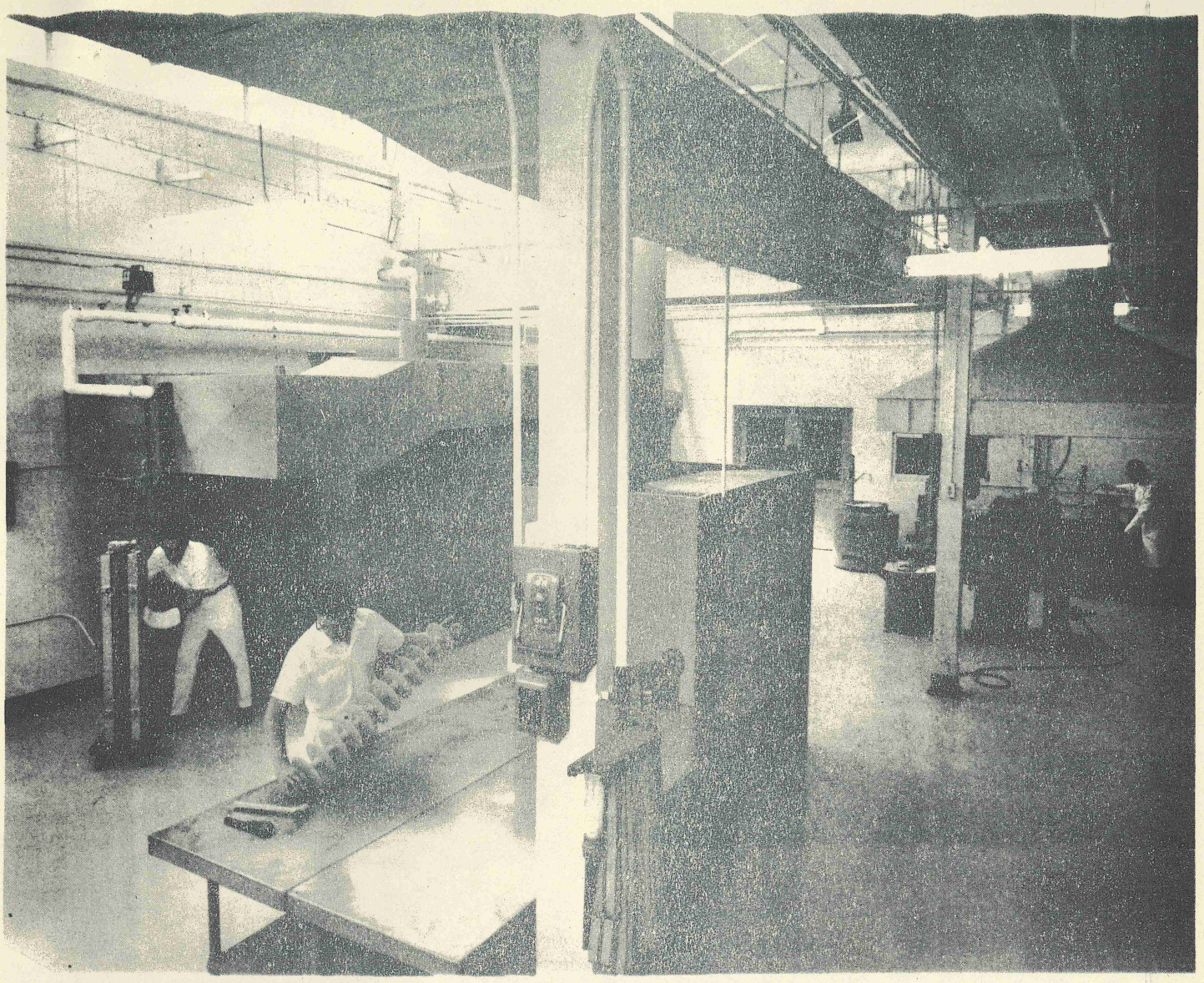
*Trademark of the General Electric Company



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1796-63-5B

(5/8/63)

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General view of General Electric's pilot shop section of its new Polymer Pilot Shop and Laboratory in Baltimore, Md., shows technician (at left) removing insulator mold from curing oven following curing cycle and technician (at right) mixing compounds for use in the new polymer experimental insulators.

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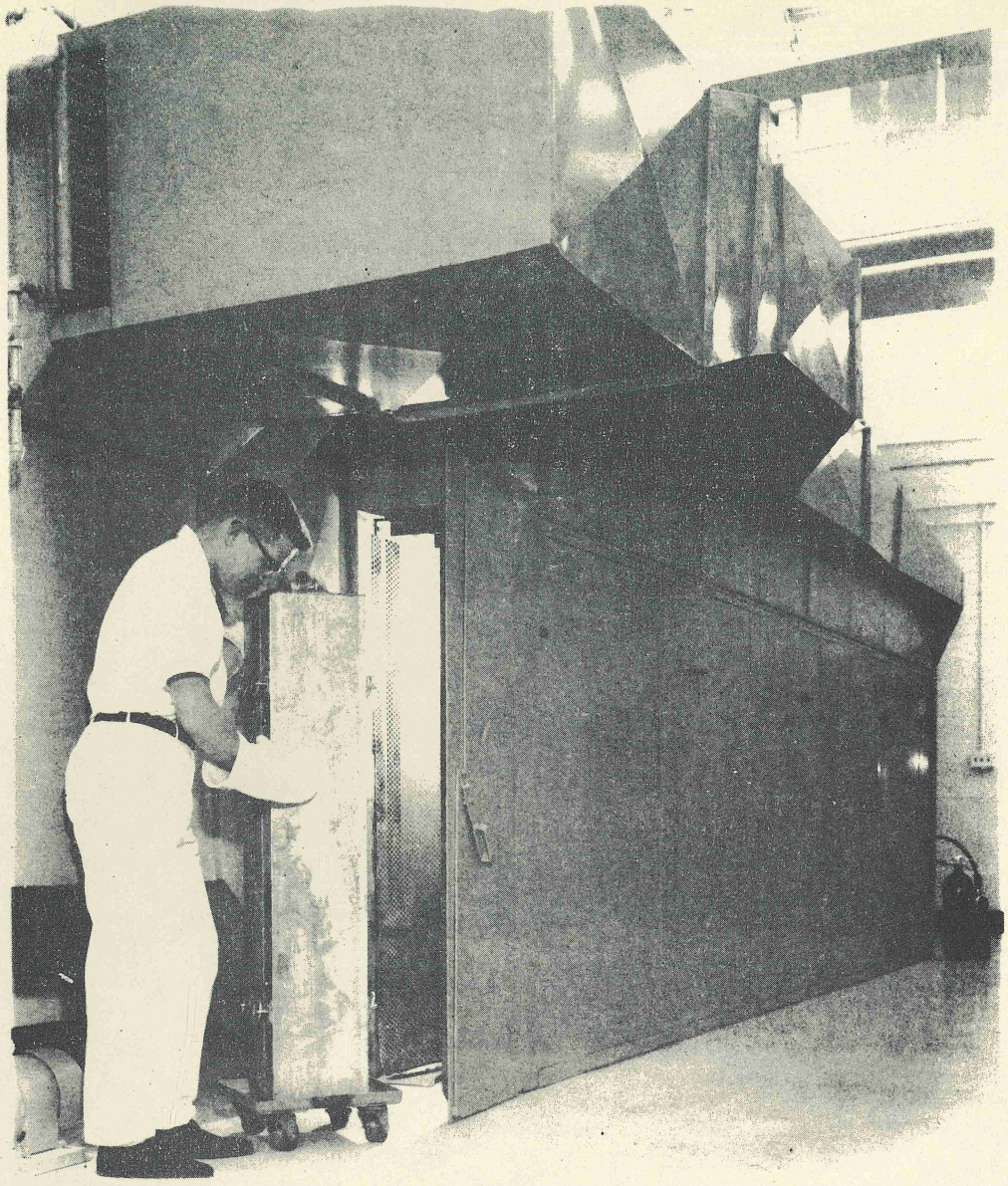
Photo No: A194046



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1796-63-5C

(5/8/63)

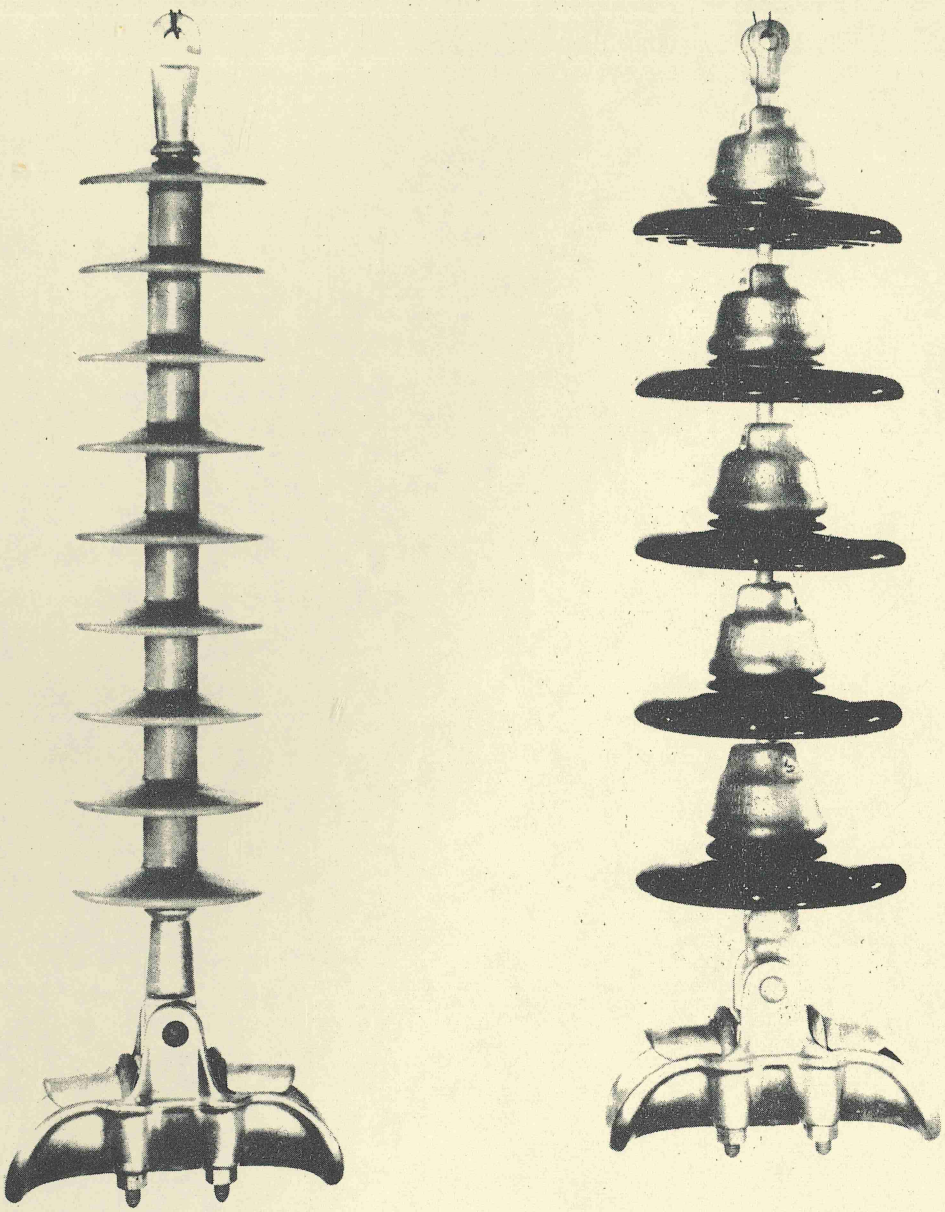
FOR IMMEDIATE RELEASE

A mold for General Electric's new polymer suspension insulator is removed by a laboratory technician from the curing oven following curing cycle at the company's new Polymer Pilot Shop and Laboratory in Baltimore, Maryland.

Complete manufacturing cycle time for new polymer suspension insulators is less than 8 hours compared to present 6 to 17-day cycle for porcelain insulators.

-30-

Photo No: A194047



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1796-63-5E

(5/8/63)

FOR IMMEDIATE RELEASE

General Electric's new polymer suspension insulator (left) called GEPOL* insulators, weigh 70 per cent less than equivalent porcelain insulators (right), are essentially puncture-proof, more heat resistant, and are far superior in impact strength.

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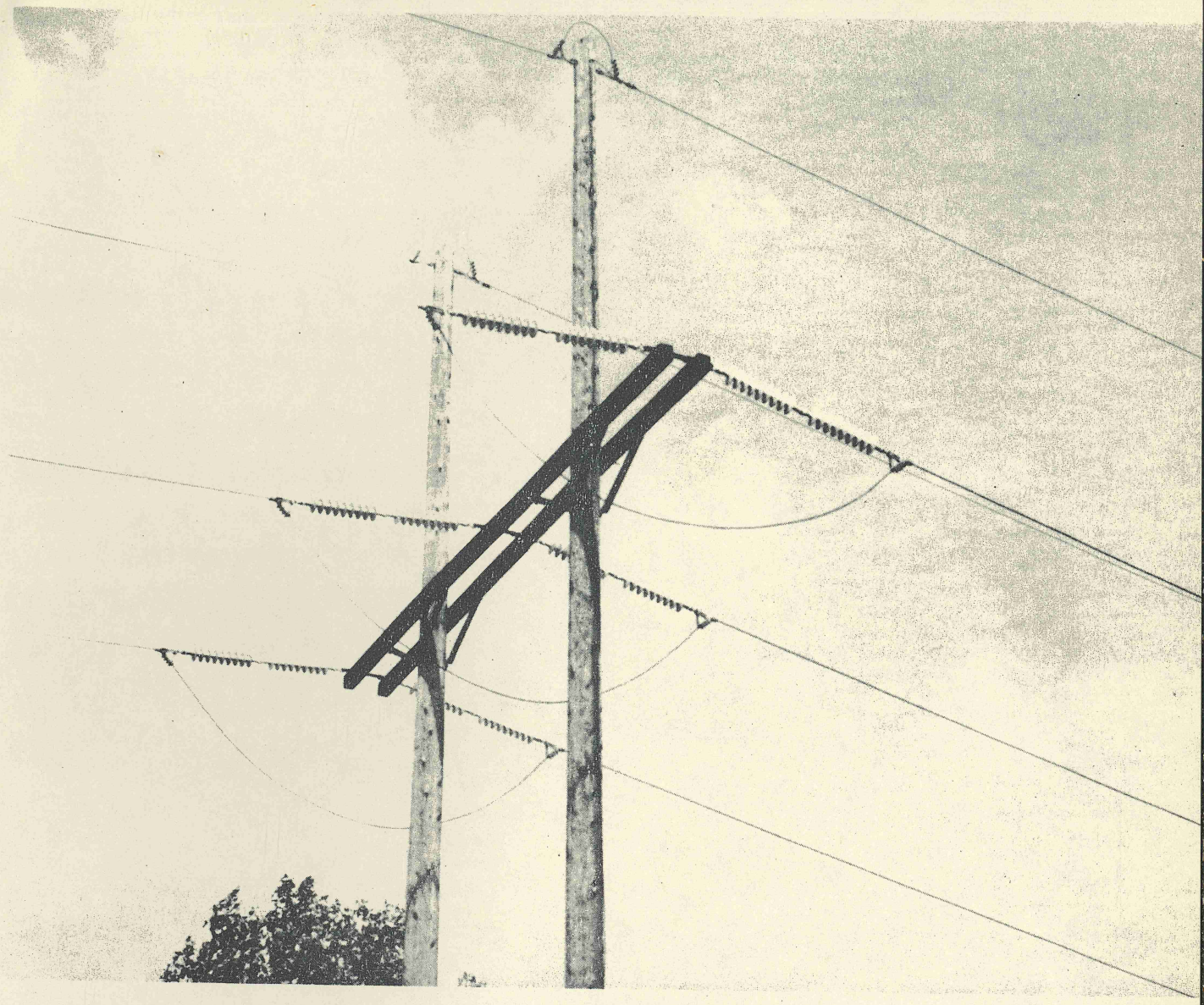
*Trademark of the General Electric Company

Photo No: 95279-1



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1796-63-5G

(5/8/63)

FOR IMMEDIATE RELEASE

General Electric's new GEPOL* insulators are shown installed on a 115 kv line of the Baltimore Gas & Electric Company. The polymer insulators were installed in March, 1959.

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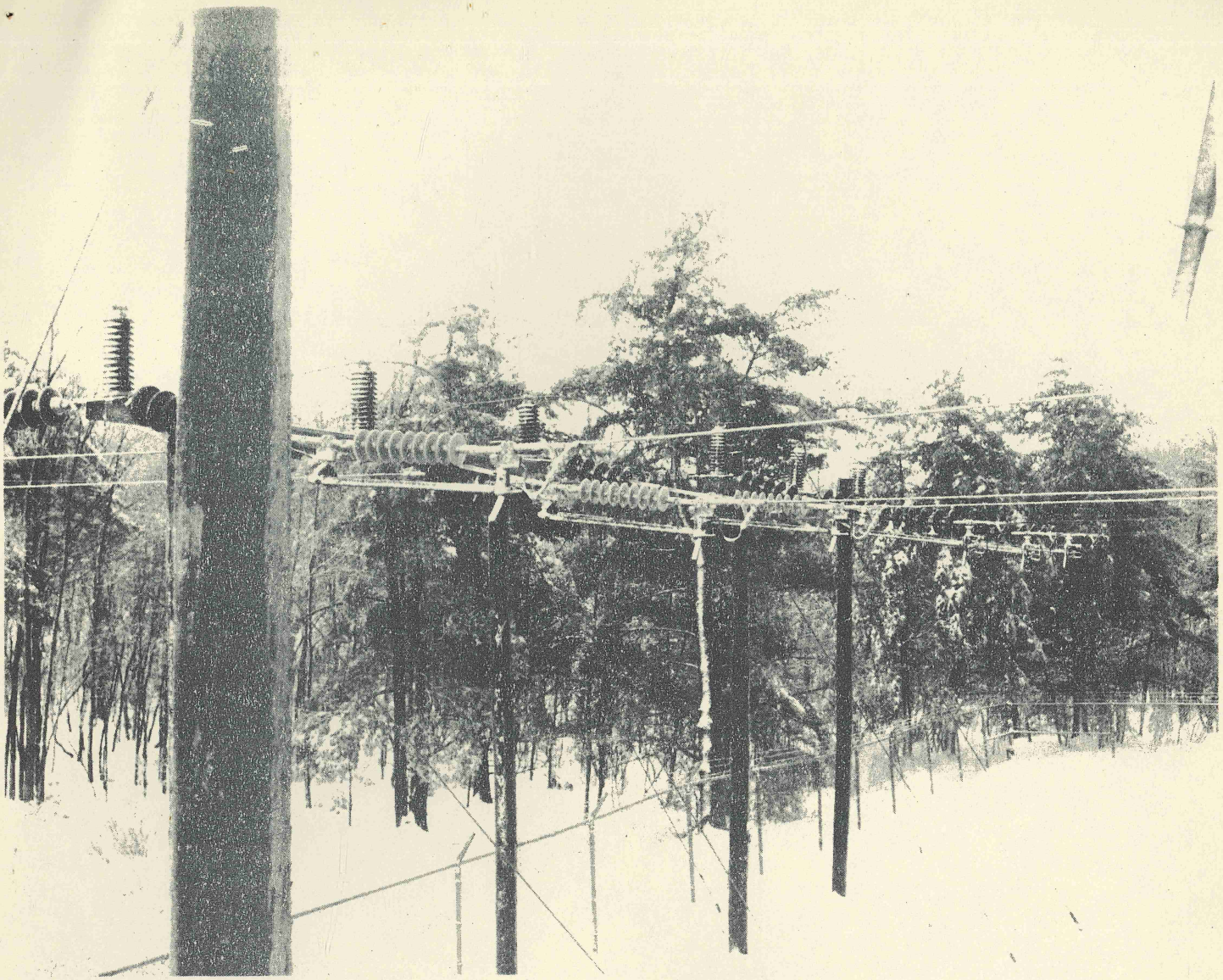
*Trademark of the General Electric Company

Photo No: A5015-1



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1796-63-5F

(5/8/63)

FOR IMMEDIATE RELEASE

A special application of General Electric's new polymer insulators are shown installed on a 69 kv line of the New England Electric System. Insulators were installed in October, 1959.

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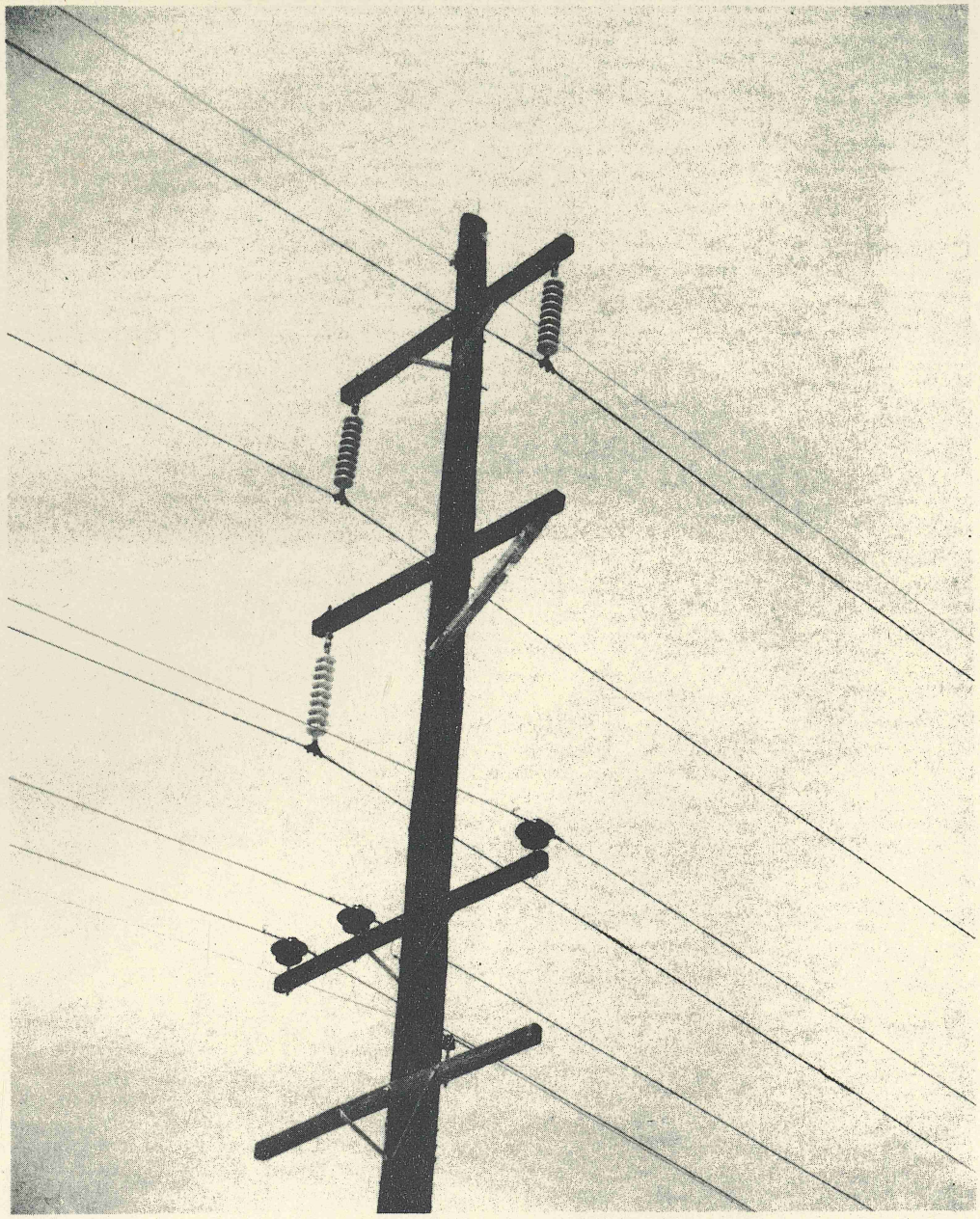
Photo No: E1012-11



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1796-63-5H

(5/8/63)

FOR IMMEDIATE RELEASE

General Electric's new polymer insulators are shown in service on a 69 kv line of the Florida Power & Light Company at Juno Beach, Florida. Insulators were installed in April, 1959.

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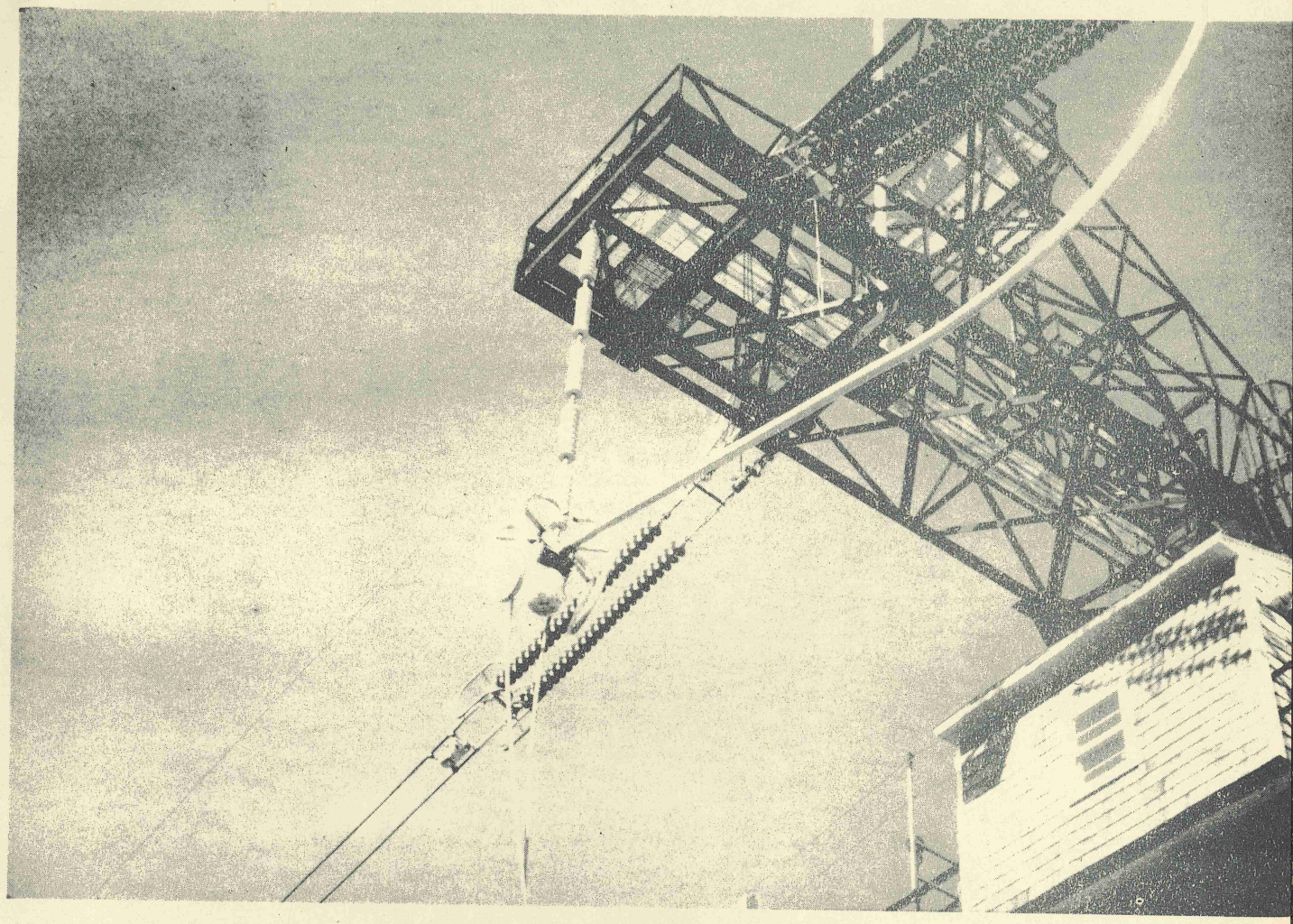
Photo No: E0922-1



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1796-63-5D

(5/8/63)

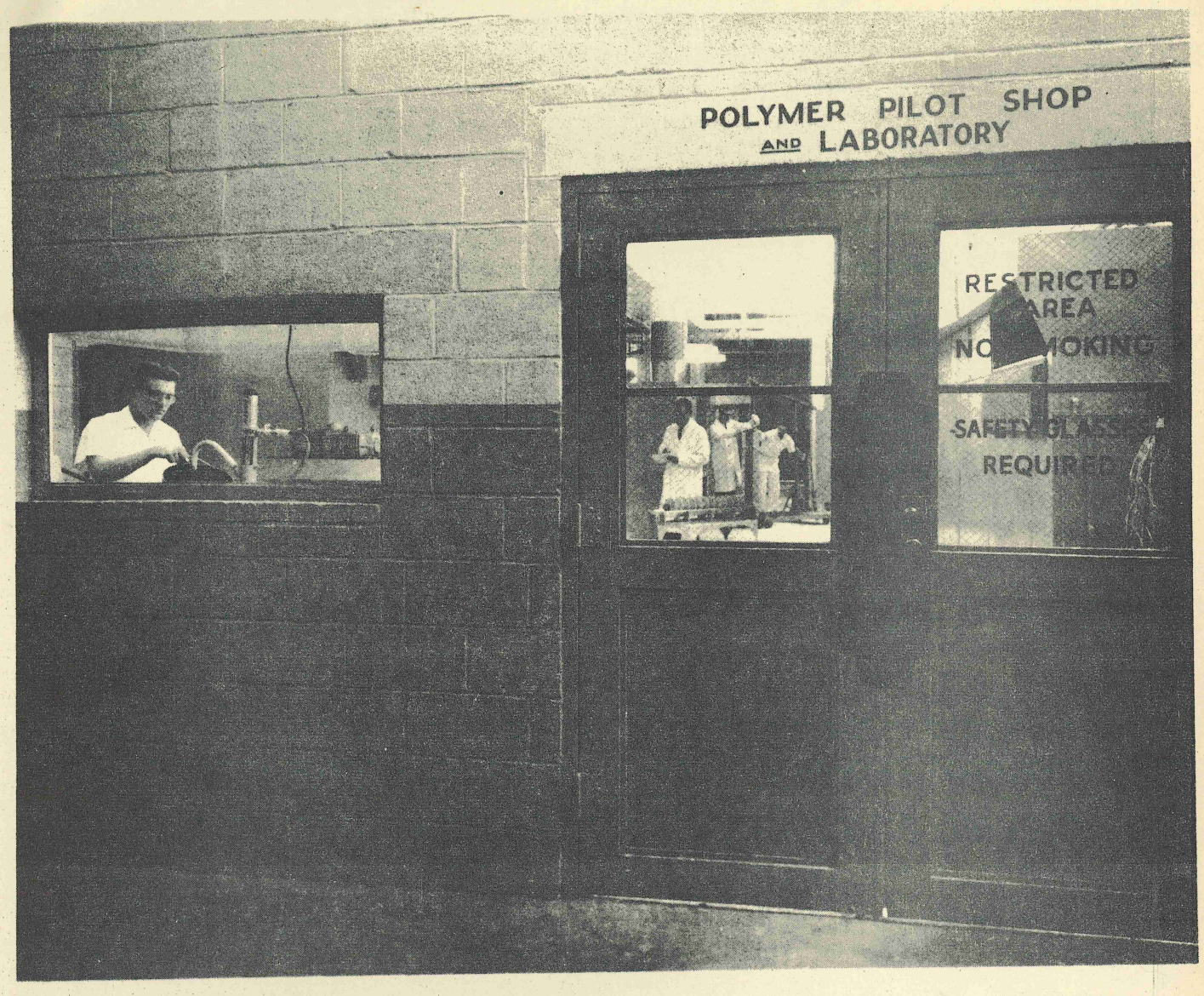
FOR IMMEDIATE RELEASE

New polymer insulators are shown on General Electric Company's Project EHV line in Pittsfield, Mass. The insulators were installed in September of 1961.

Test line was energized in January, 1962 and has been energized at 500 kv to 525 kv for approximately half the time since that date.

-30-

Photo No: E0939



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1796-63-5A

(5/8/63)

FOR IMMEDIATE RELEASE

External view looking into General Electric's new $100,000 Polymer Pilot Shop and Laboratory shows clean-room type techniques which will be used in the pilot shop production of the more than 1,000 GEPOL* suspension insulators which will go to utilities who will make field trial installations the remainder of this year and during 1964.

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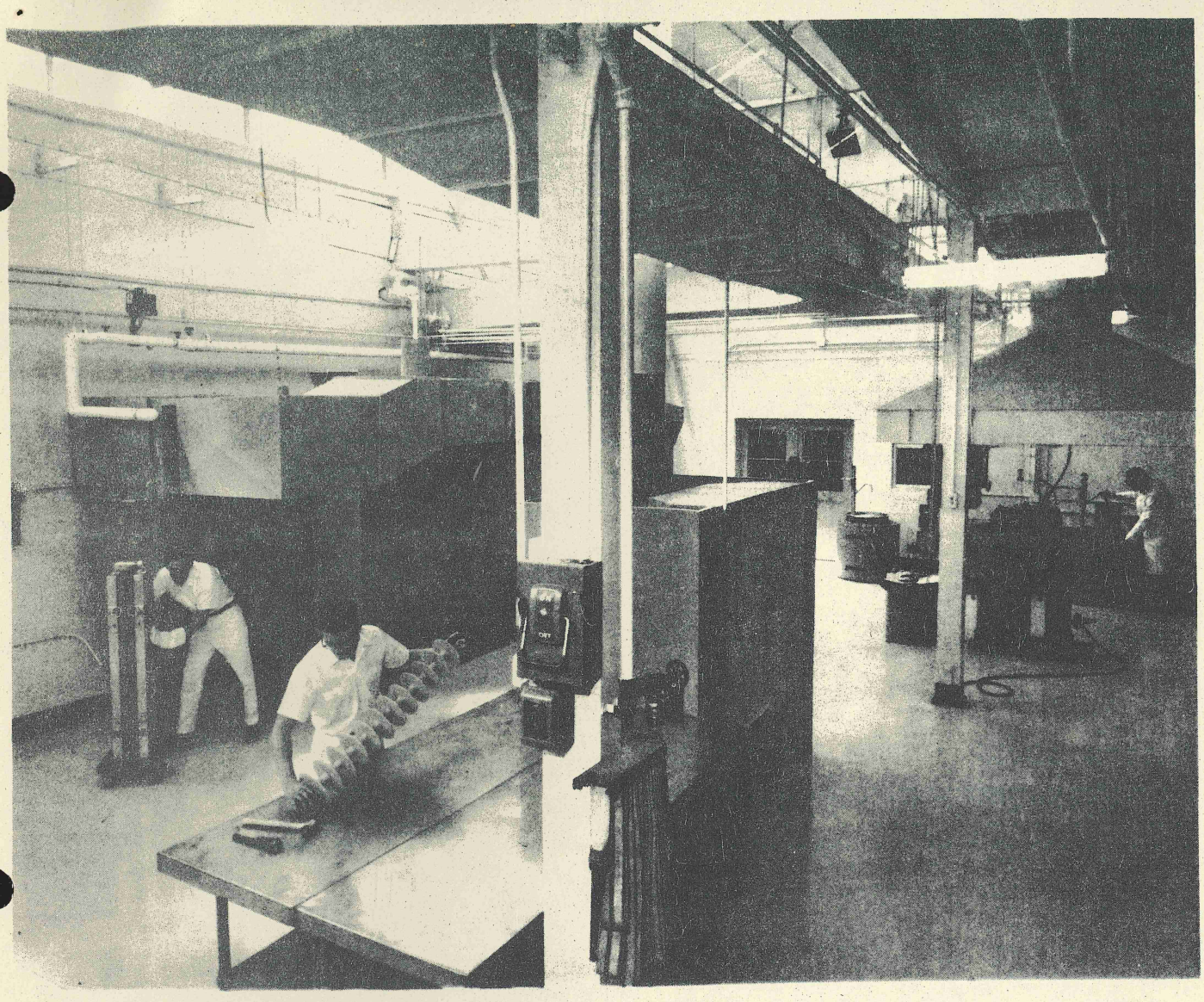
*Trademark of the General Electric Company

Photo No: A194045



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1796-63-5B

(5/8/63)

FOR IMMEDIATE RELEASE

General view of General Electric's pilot shop section of its new Polymer Pilot Shop and Laboratory in Baltimore, Md., shows technician (at left) removing insulator mold from curing oven following curing cycle and technician (at right) mixing compounds for use in the new polymer experimental insulators.

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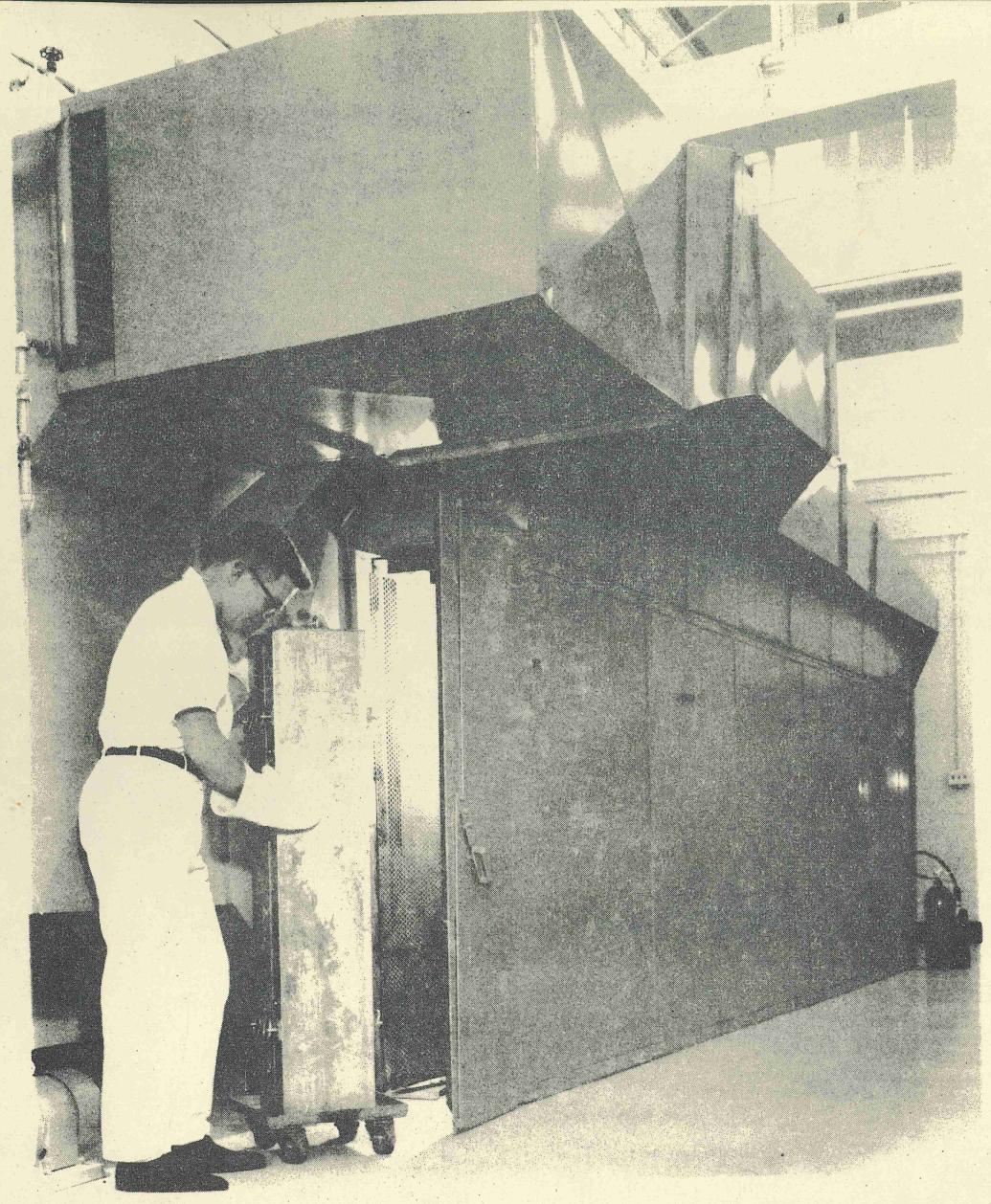
Photo No: A194046



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1796-63-5C

(5/8/63)

FOR IMMEDIATE RELEASE

A mold for General Electric's new polymer suspension insulator is removed by a laboratory technician from the curing oven following curing cycle at the company's new Polymer Pilot Shop and Laboratory in Baltimore, Maryland.

Complete manufacturing cycle time for new polymer suspension insulators is less than 8 hours compared to present 6 to 17-day cycle for porcelain insulators.

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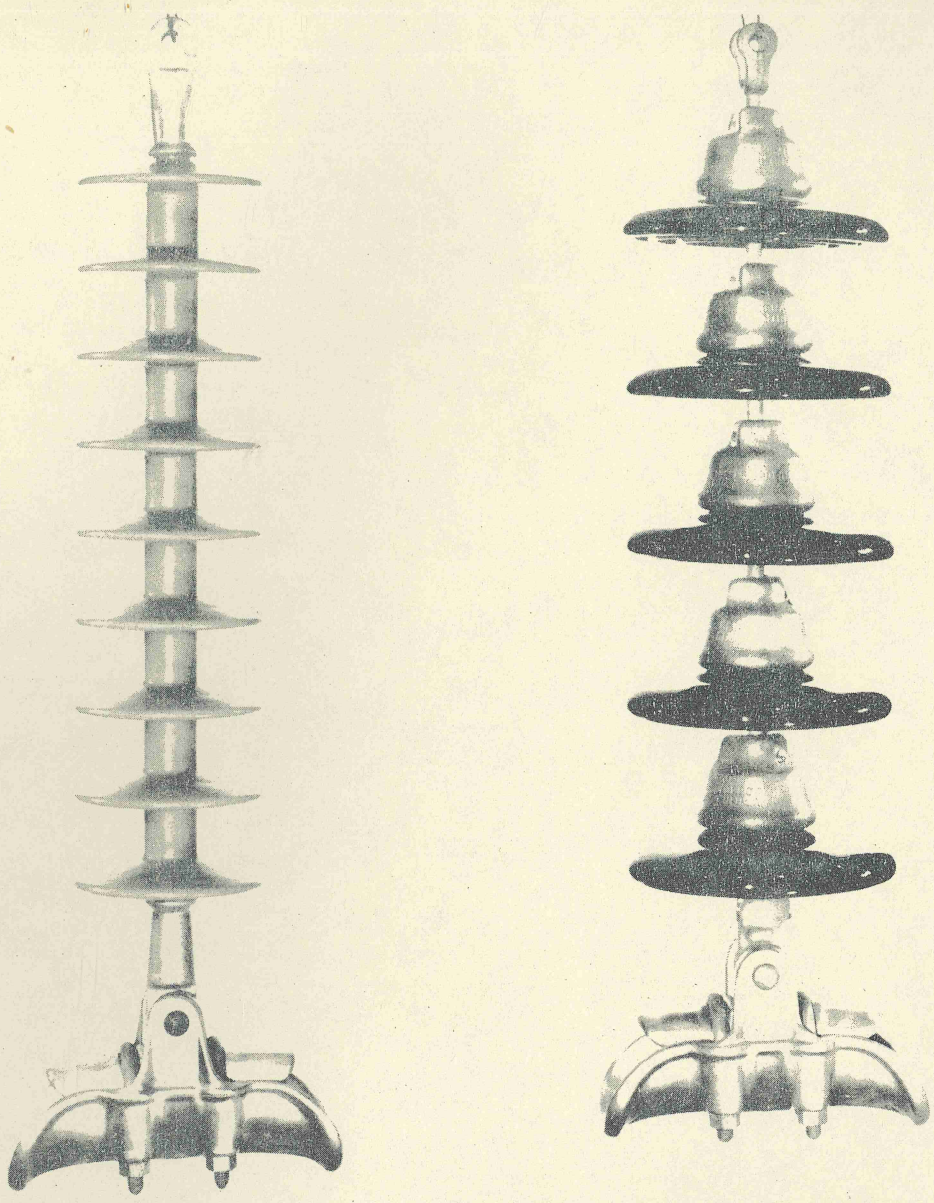
Photo No: A194047



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1796-63-5E

(5/8/63)

FOR IMMEDIATE RELEASE

General Electric's new polymer suspension insulator (left) called GEPOL* insulators, weigh 70 per cent less than equivalent porcelain insulators (right), are essentially puncture-proof, more heat resistant, and are far superior in impact strength.

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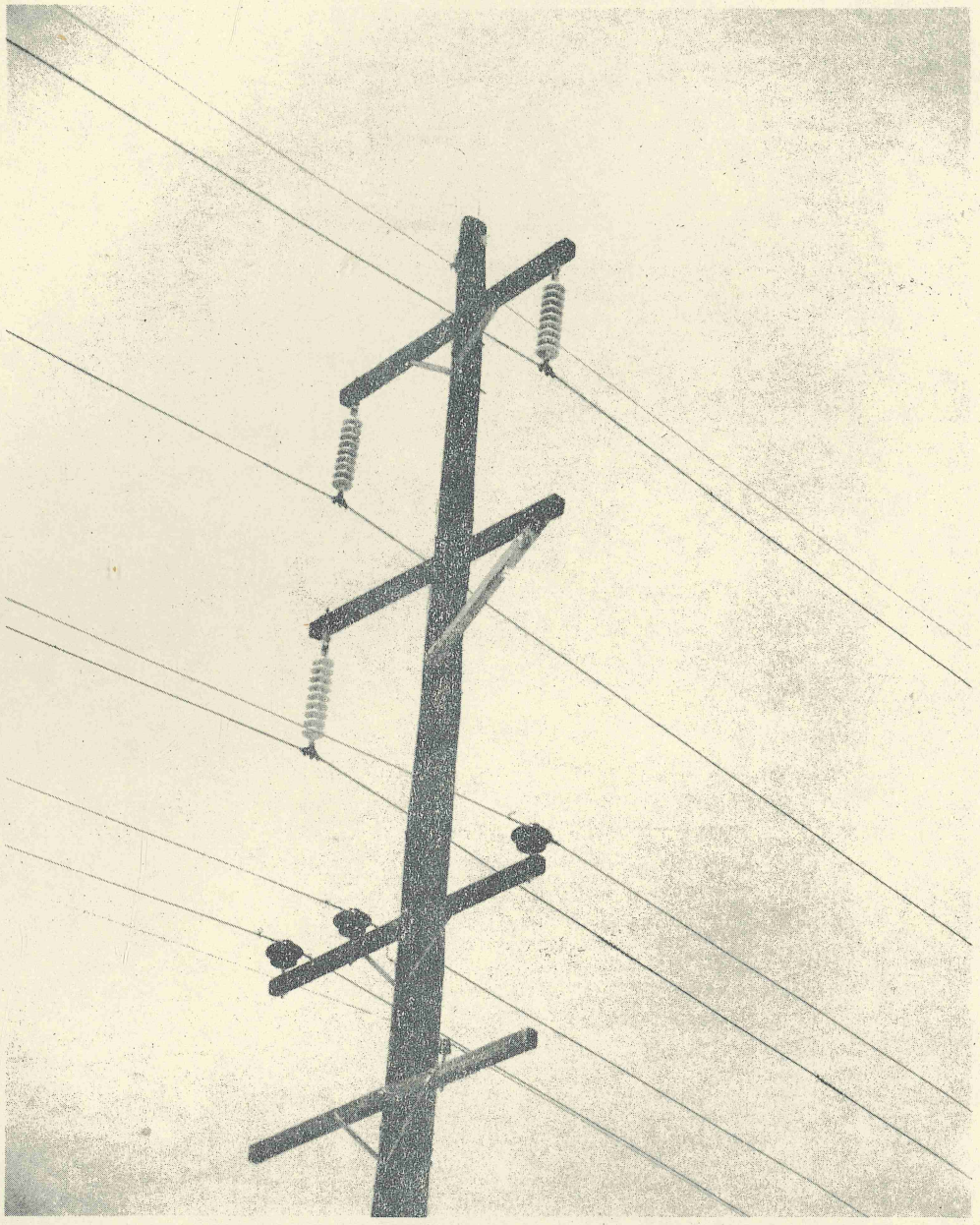
*Trademark of the General Electric Company

Photo No: 95279-1



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Schenectady 5, New York

1796-63-5H

(5/8/63)

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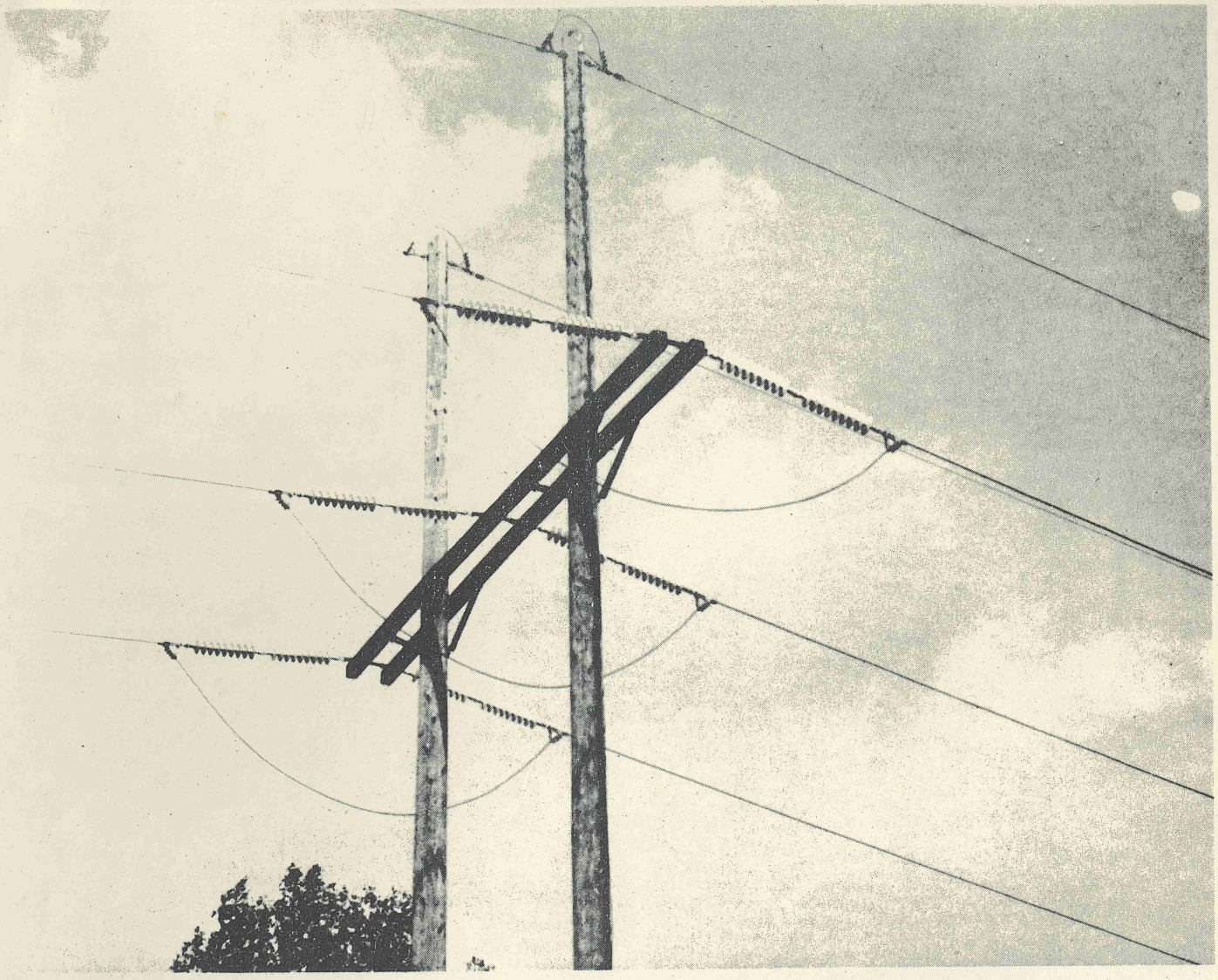
General Electric's new polymer insulators are shown in service on a 69 kv line of the Florida Power & Light Company at Juno Beach, Florida. Insulators were installed in April, 1959.



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1796-63-5G

(5/8/63)

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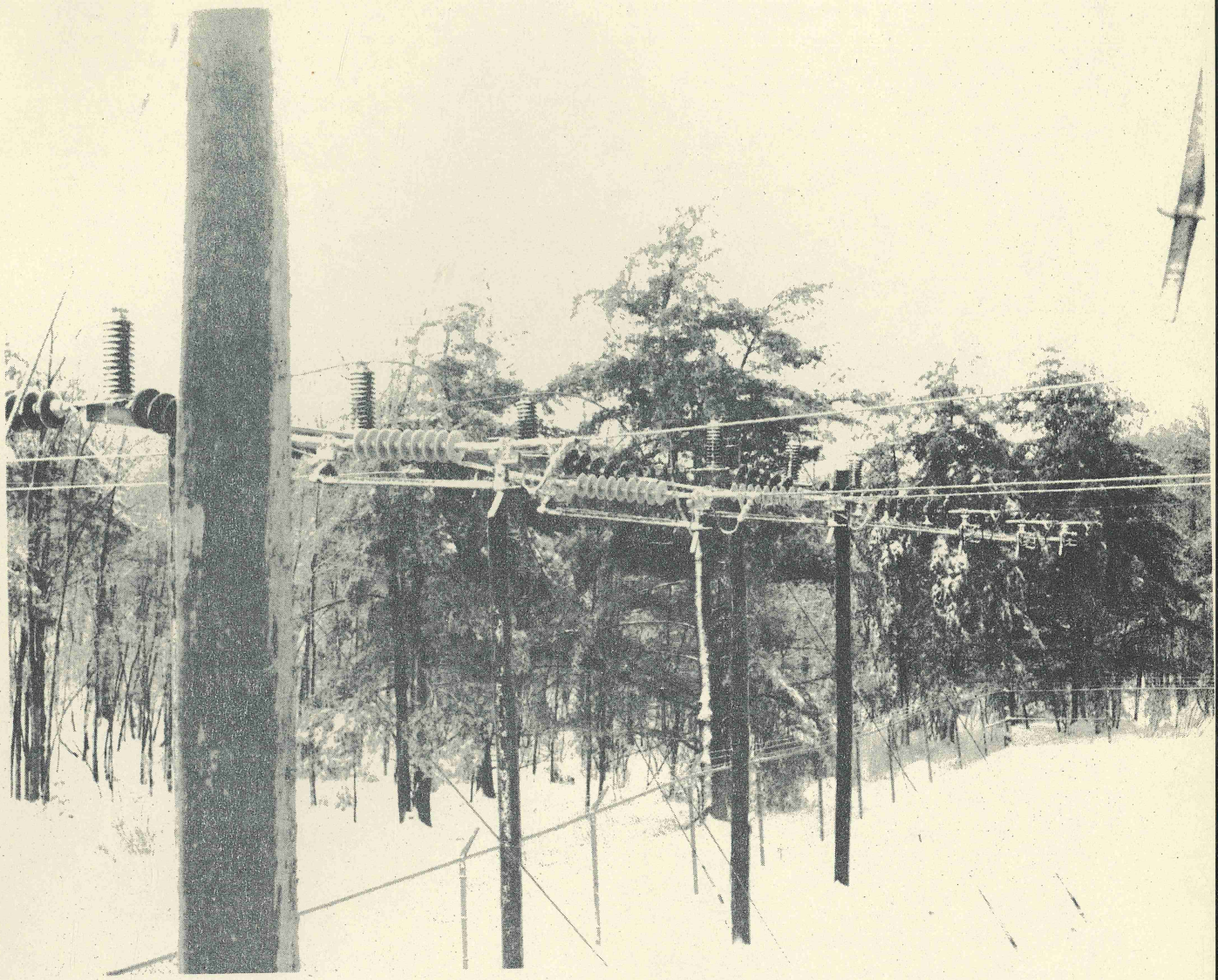
General Electric's new GEPOL* insulators are shown installed on a 115 kv line of the Baltimore Gas & Electric Company. The polymer insulators were installed in March, 1959.

-30-

*Trademark of the General Electric Company

Photo No: A5015-1



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1796-63-5F

(5/8/63)

FOR IMMEDIATE RELEASE

A special application of General Electric's new polymer insulators are shown installed on a 69 kv line of the New England Electric System. Insulators were installed in October, 1959.

-30-

Photo No: E1012-11

News Bureau (R.B. Piorkowski)
GENERAL ELECTRIC COMPANY
Schenectady 5, New York

1796-63-5D

(5/8/63)

FOR IMMEDIATE RELEASE

New polymer insulators are shown on General Electric Company's Project EHV line in Pittsfield, Mass. The insulators were installed in September of 1961.

Test line was energized in January, 1962 and has been energized at 500 kv to 525 kv for approximately half the time since that date.

-30-

Photo No: E0939

GENERAL ELECTRIC

INSULATOR DEPARTMENT

Baltimore, March 26, 1963

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On February 13, 1963, at Fort Meade, Md., our Engineering Section staged a test to determine the relative resistance of several insulating structures to gunfire. All firing was done by expert riflemen stationed at Ft. Meade. Tests were conducted on each of the following:

1. Lapp Strut Insulator, Cat. No. 73770, a 12 unit equivalent suitable for 230 kv application, 15,000 lb. ultimate tensile strength.

2. Locke Unispar, Cat. No. 18713, a 13 unit strut suitable for 230 kv application, 13,000 lb. ultimate tensile strength.

3. Locke unit-type Polymer suspension insulator (developmental) suitable for 69 kv application, 15,000 lb. ultimate tensile strength.

All shots were made at a distance of 60 feet. The guns and ammunition used were as follows:

1. 22 long rifle - 40 grain lead match bullet, velocity 1300 ft./sec.

2. 45 cal. service pistol - 230 grain lead match bullet, velocity 830 ft./sec.

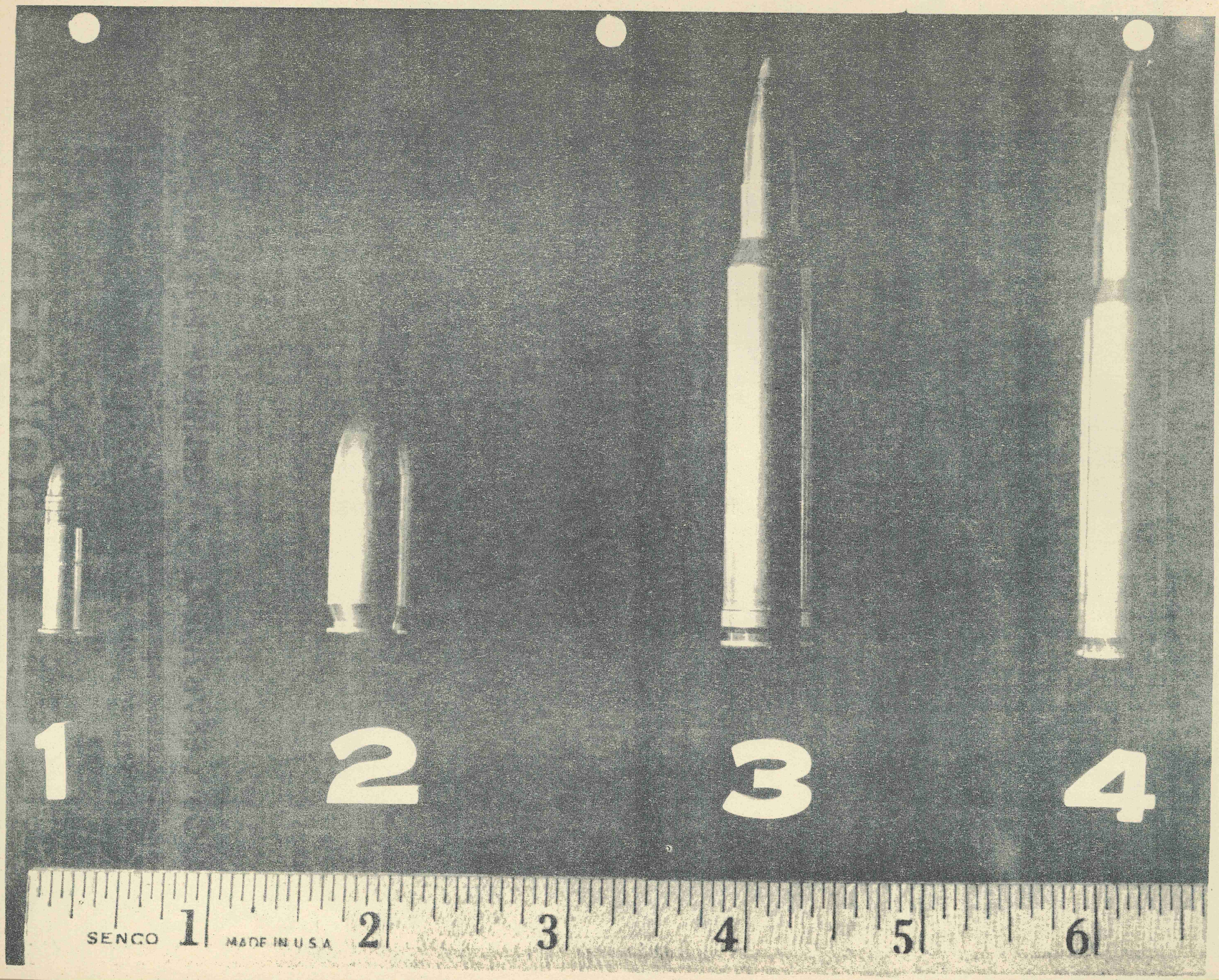
3. 308 Magnum service rifle - 180 grain lead match bullet, velocity 2650 ft./sec.

4. 30 cal. type M-1 service rifle - 173 grain lead bullet, velocity 2640 ft./sec.

The first firings were made at the bottom of each insulator structure, and successive shots were made up the structure as to be hitting undamaged parts as the tests progressed.

The following series of photographs show the damage sustained by each of the insulators.

ACCENT ON VALUE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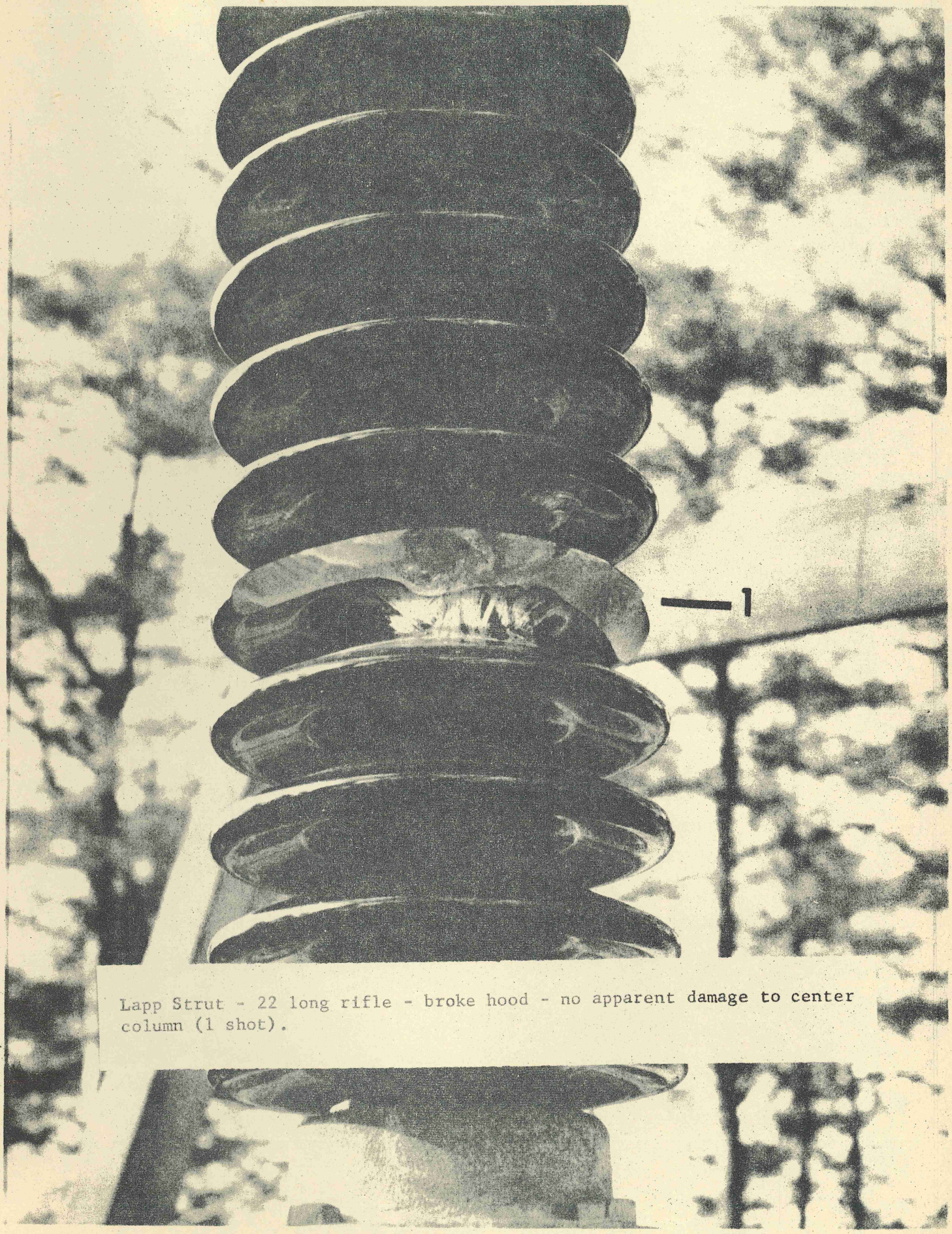
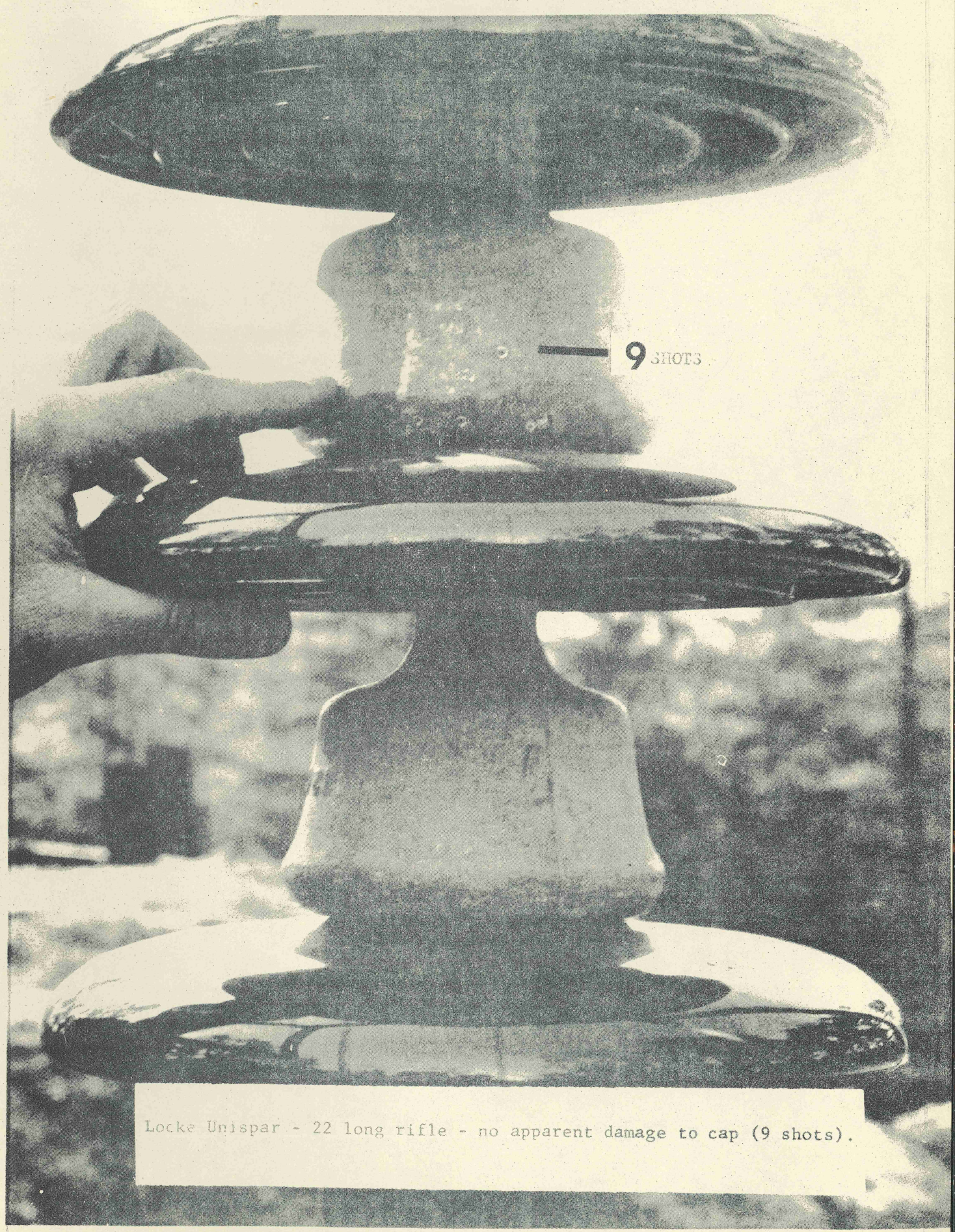
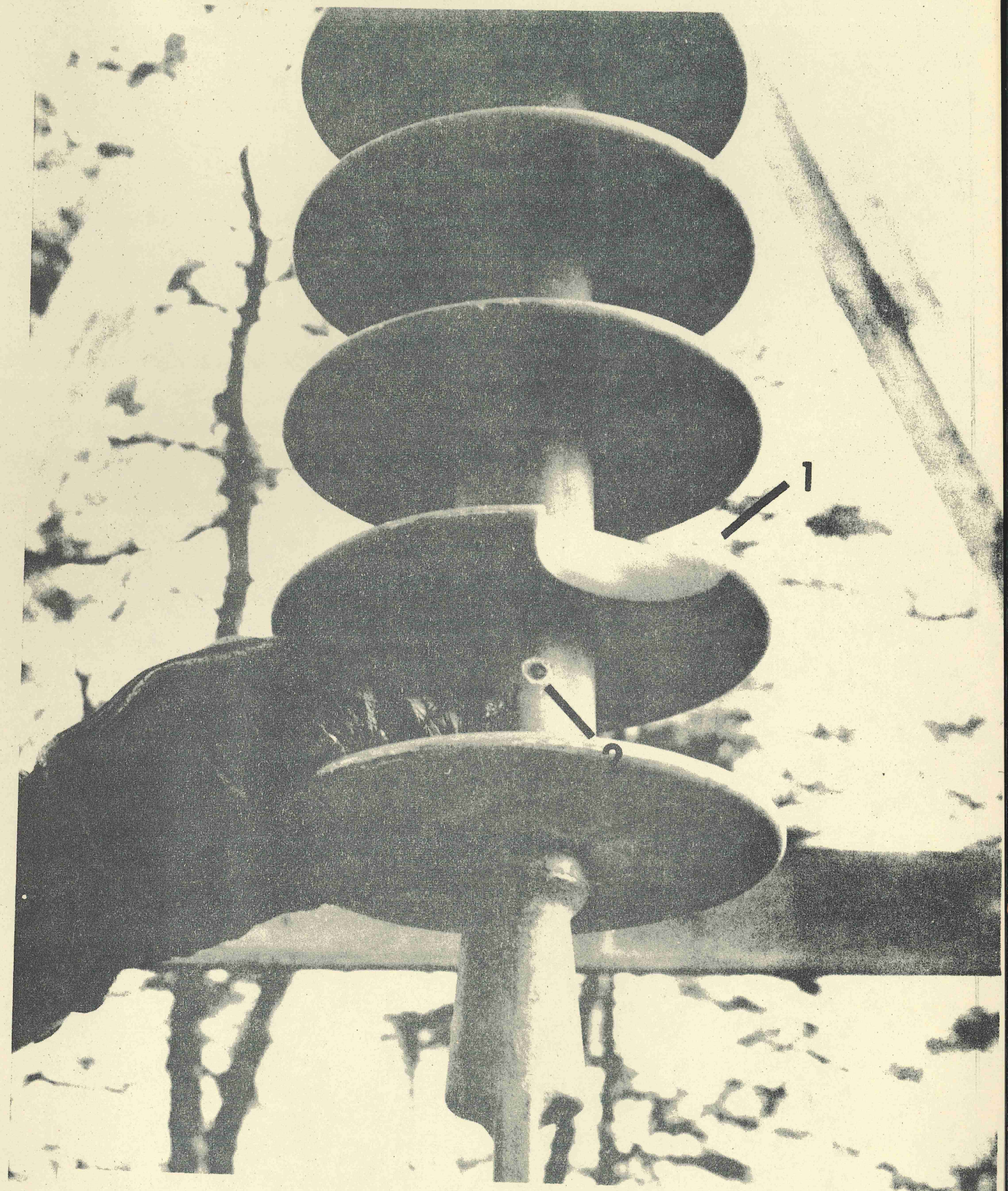


Lapp Strut - 22 long rifle - broke hood - no apparent damage to center column (1 shot).

Locke Unispar - 22 long rifle - no apparent damage to shell or cap (5 shots).

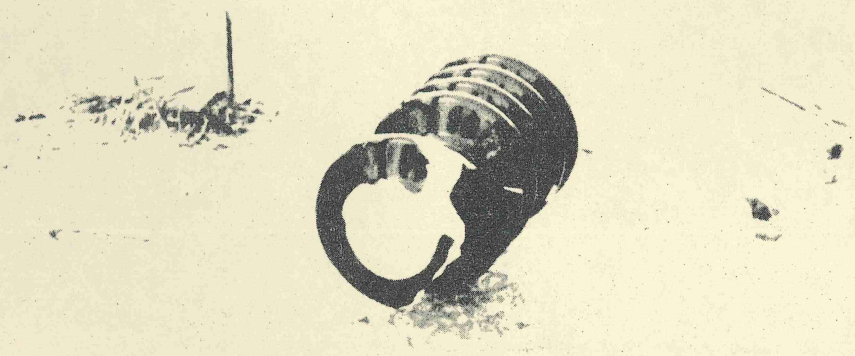


Locke Unispar - 22 long rifle - no apparent damage to cap (9 shots).

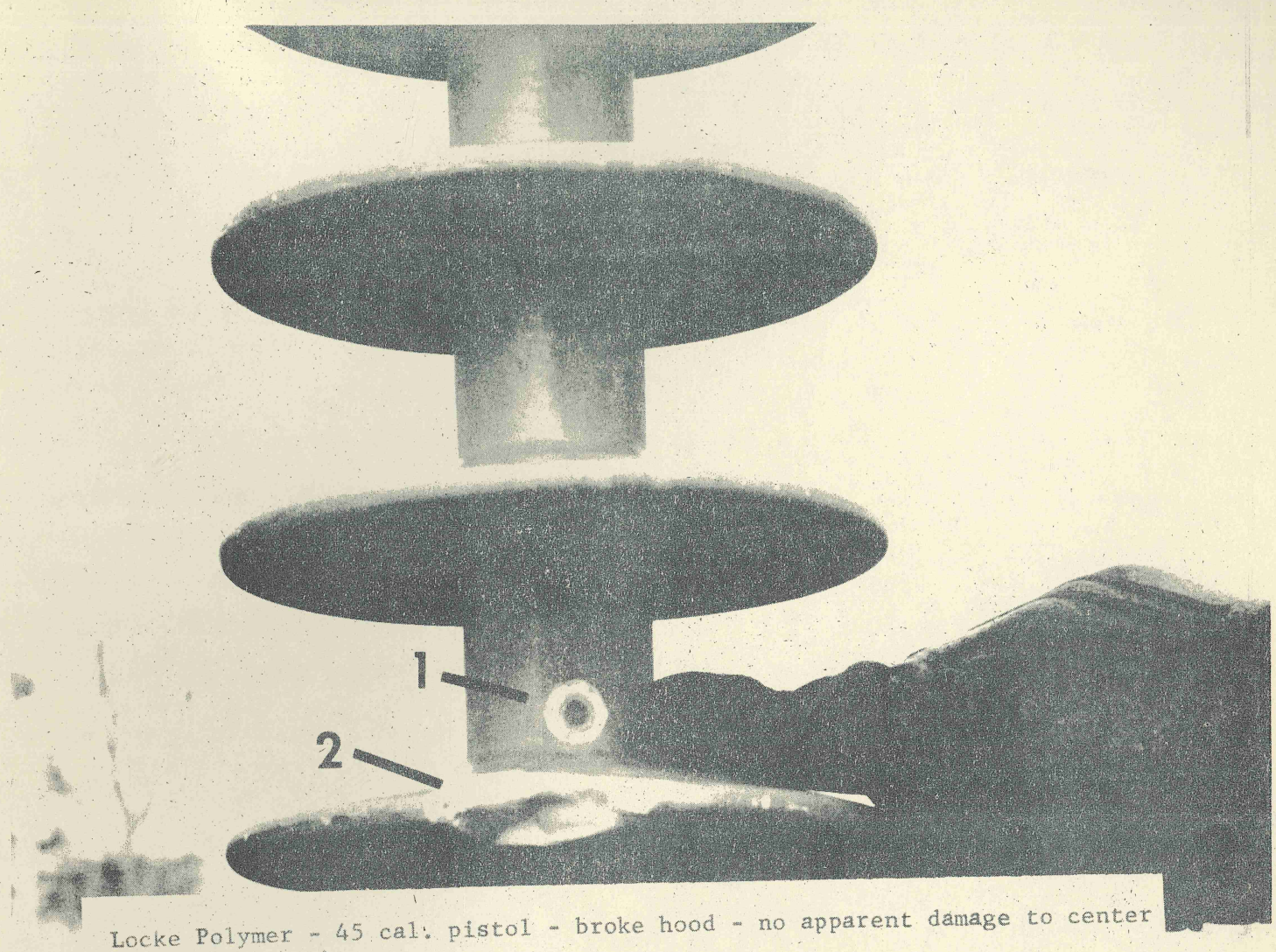


Locke Polymer - 22 long rifle - broke hood - no apparent damage to center column (2 shots).

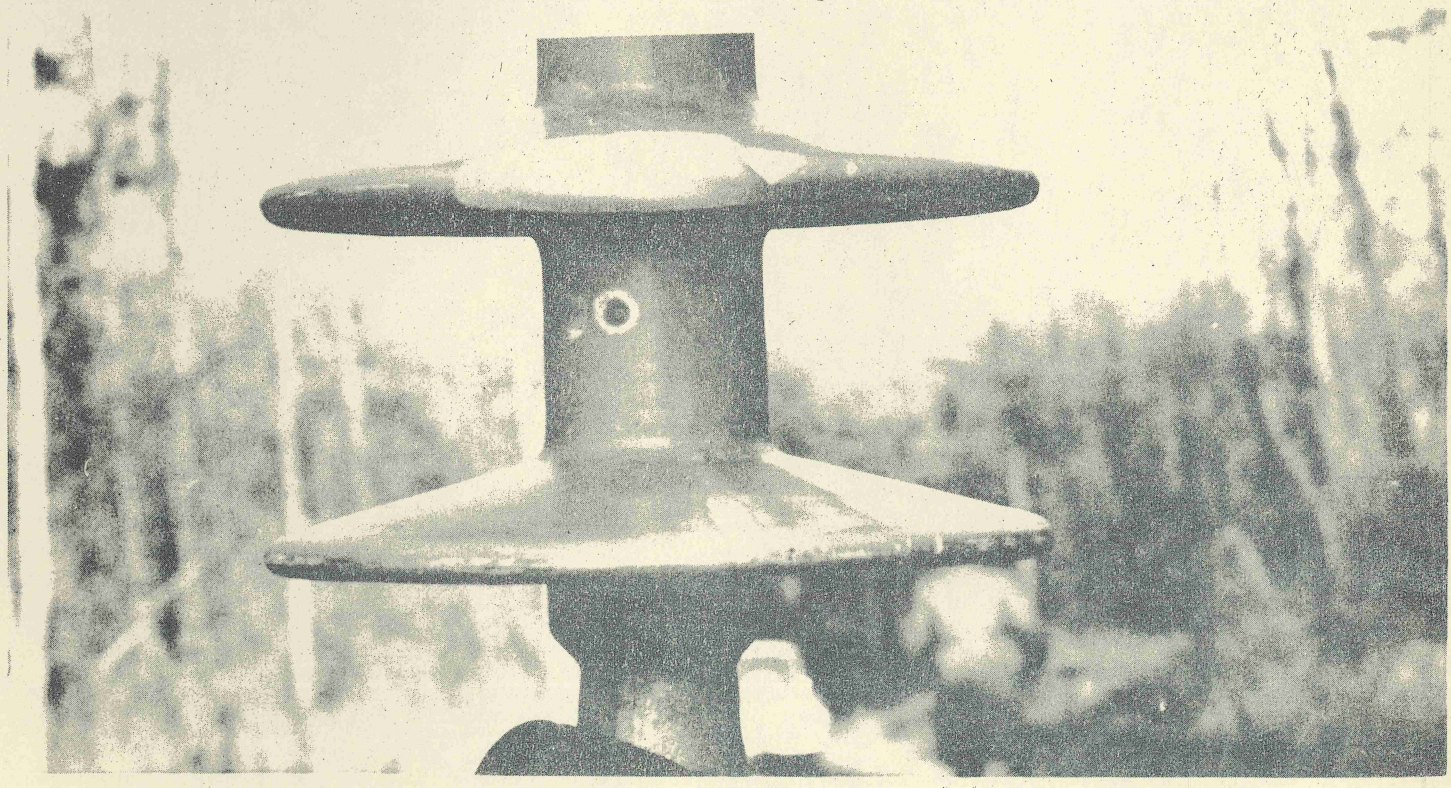
Lapp Strut - 45 cal. pistol - broke bottom insulator (1 shot).



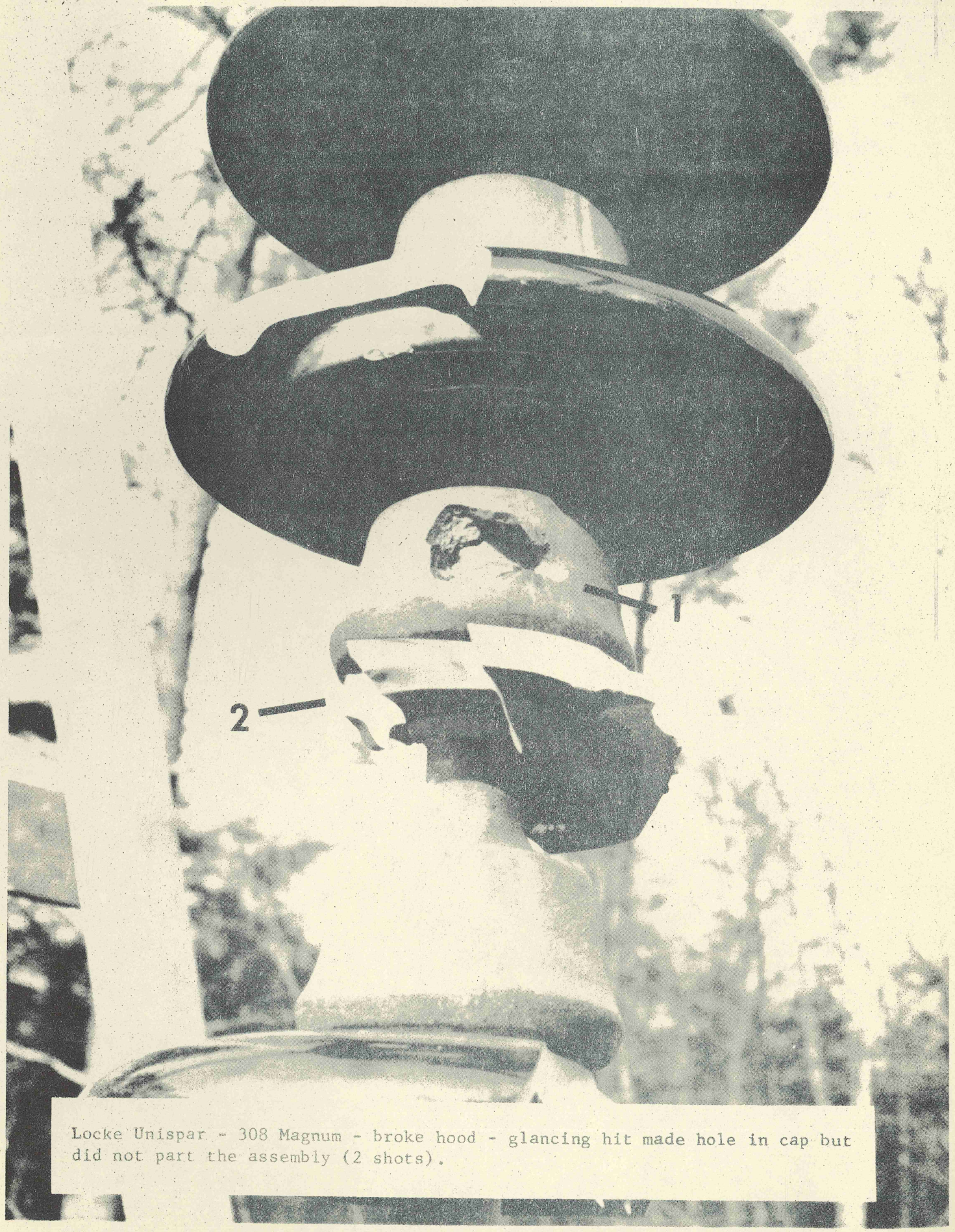
Locke Unispar - 45 cal. pistol - broke off two shells - no apparent damage to cap. Direct hit on bell head of insulator - no damage (5 shots).



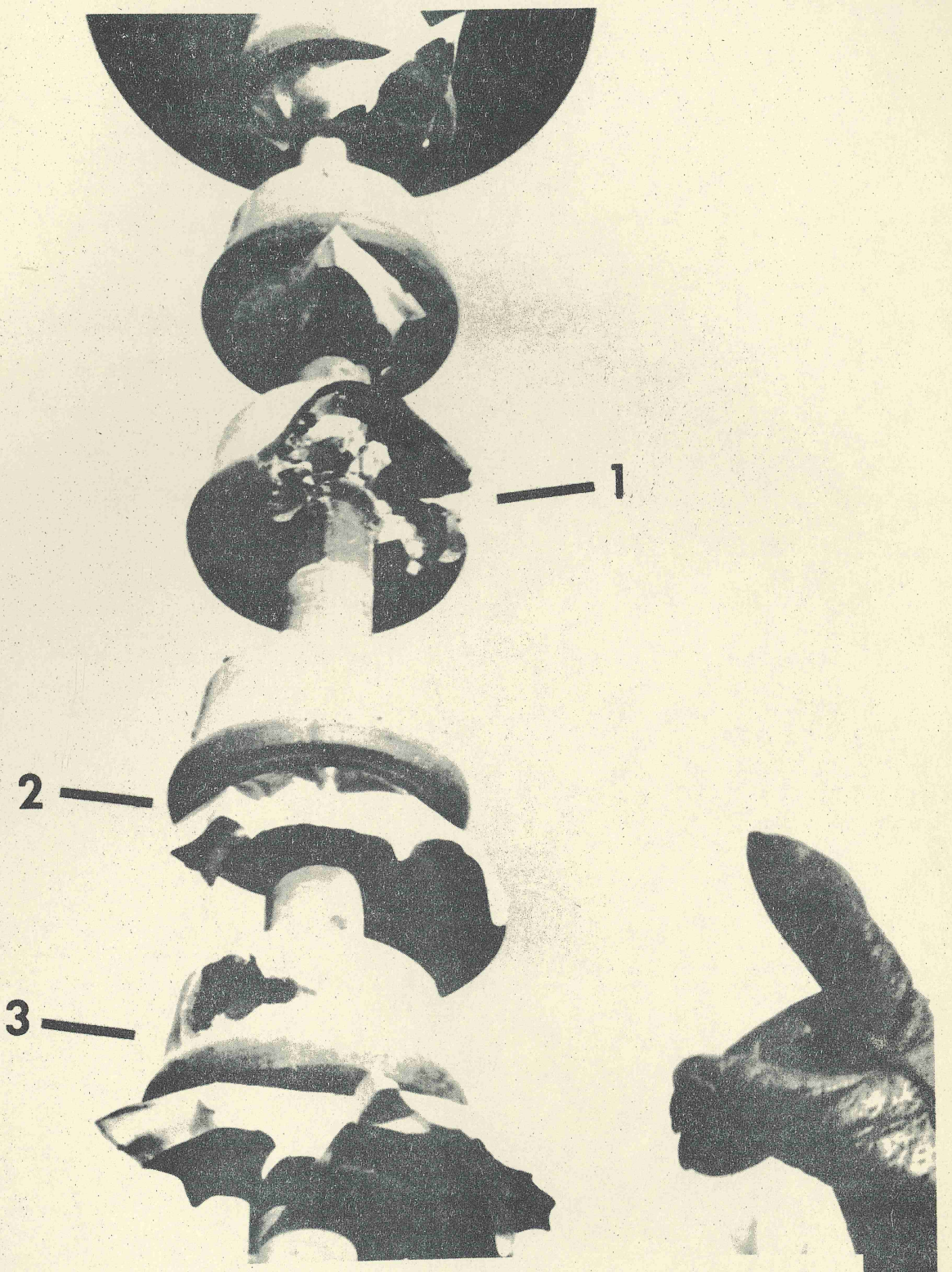
Locke Polymer - 45 cal. pistol - broke hood - no apparent damage to center column (2 shots).



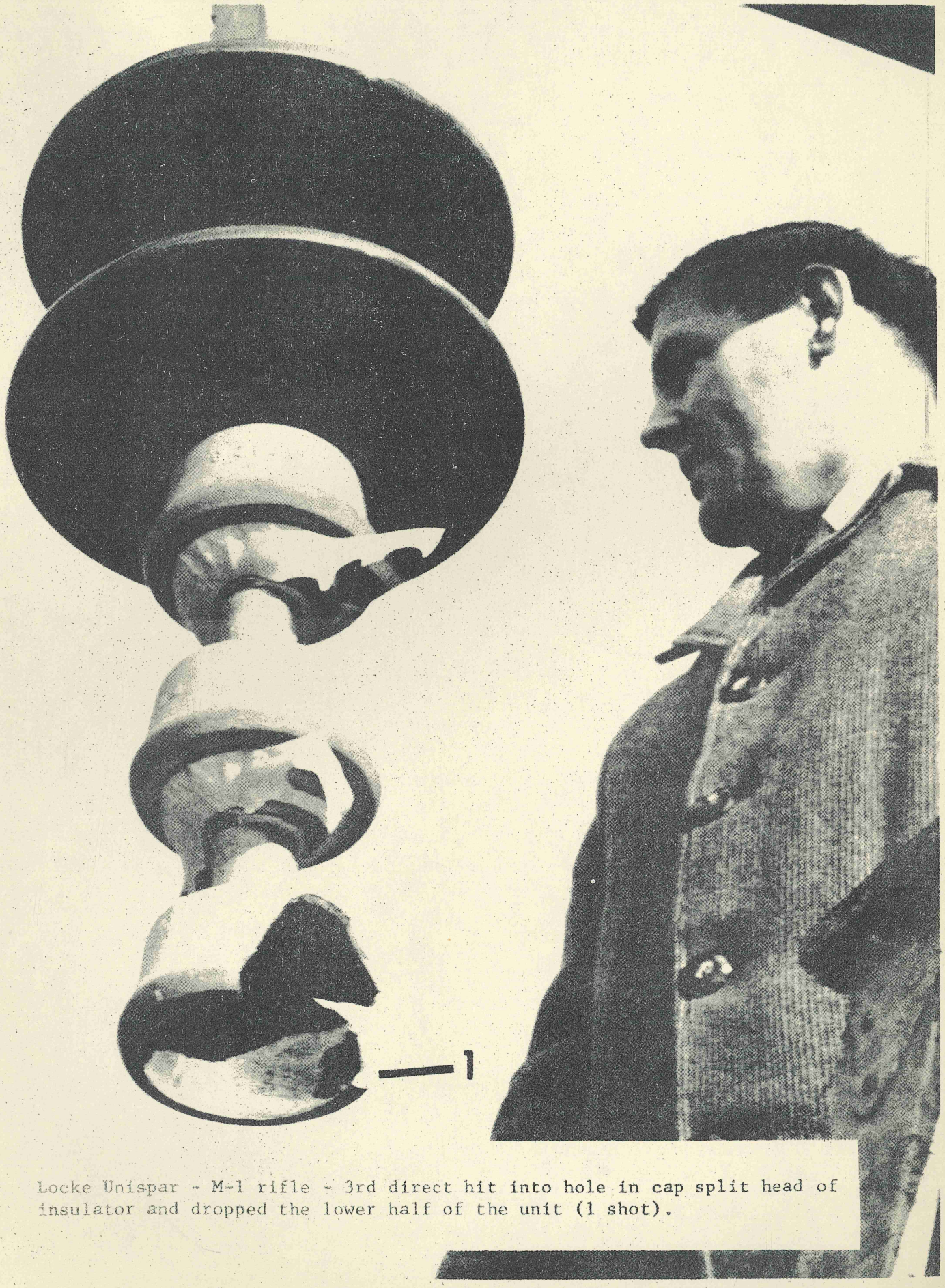
Lapp Strut - 308 Magnum - broke remaining section into several parts (1 shot)



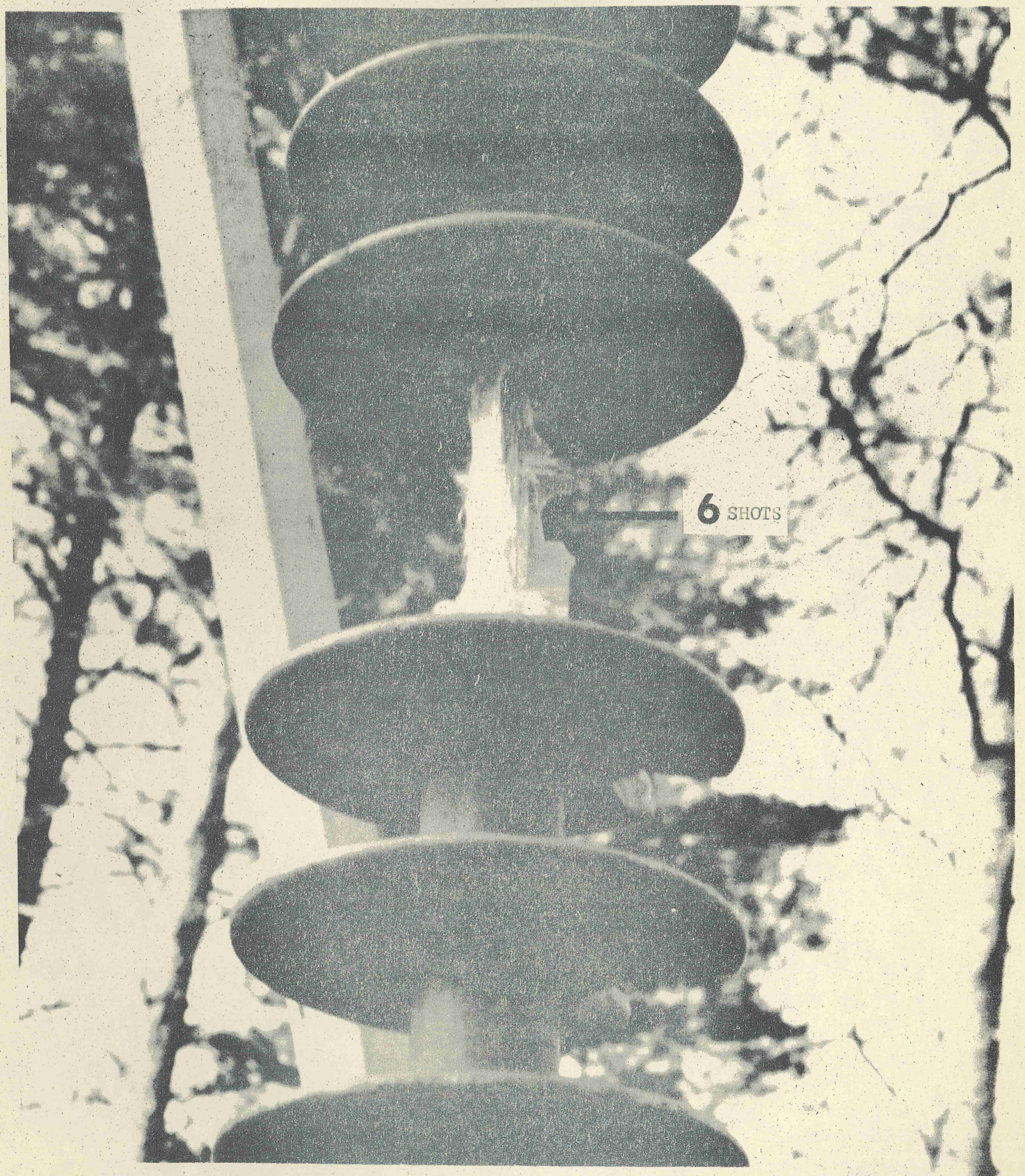
Locke Unispar - 308 Magnum - broke hood - glancing hit made hole in cap but did not part the assembly (2 shots).



Locke Unispar - M-1 rifle - broke additional hoods - tore out side of cap - assembly ready to drop (3 shots).



Locke Unispar - M-1 rifle - 3rd direct hit into hole in cap split head of insulator and dropped the lower half of the unit (1 shot).



Locke Polymer - M-1 rifle - broke hood, stripped cast epoxy from glass fibre core, and broke some strands of glass fibre (6 shots).

Summary

As was expected, very little damage was done by the 22 long rifle fire. The post insulator, with relatively thin hood sections, sustained damage to the hoods but apparently none to the central core. The Locke Unispar had no damage on several successive firings, either due to hits on the porcelain shells or on the caps. The Polymer unit, again with relatively thin hoods, sustained limited breakage of the hoods, but no damage to the core.

The 45 caliber pistol was sufficient to break the post insulator, but could only break the hoods (shells) of either the Unispar or Polymer insulators - even with direct hits on the caps of the Unispar and the core of the Polymer unit.

In this test, it took successive hits by the M-1 rifle on the same cap to finally break the Unispar insulator. Even this punishment failed to destroy the integrity of the Polymer unit.

Our general conclusion for this series of tests is simply that the Unispar insulator, with its suspension-like design, also achieves suspension-like performance in its resistance to the damaging effects of gunfire. When struts are to be used in areas subject to high-velocity impact forces, such as golf balls or rifle fire, consideration should certainly be given to this advantage of the Unispar construction. We are not trying to downgrade the quality of the Lapp post - one of our own manufacture would probably perform similarly. Rather, we are showing the ability of different designs - all suitable for the same application - to withstand this one test.

J. O. Sweeny
Manager - Marketing

ml

Conference Paper

A POLYMER INSULATOR FOR HIGH VOLTAGE TRANSMISSION LINES

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63-1039

A POLYMER INSULATOR FOR HIGH VOLTAGE TRANSMISSION LINES

F. C. Vose F. S. Nichols

SUMMARY

Porcelain has been the principal insulating element in suspension insulators for many years. This paper describes how a modified epoxy type polymer with a fiberglass core is used in the design of a developmental suspension insulator for application on future transmission lines. Included in the paper is a resume of certain special tests run to prove the insulator, and a review of its current service record. The potential advantages of this type of insulator are summarized.

INTRODUCTION

Wet process electrical porcelain has been used in all types of suspension insulators for many years. Its long life, high dielectric strength, imperviousness to most chemicals, resistance to electrical tracking, and low materials cost have retained for porcelain a unique position as the insulating element in suspension insulators. There are probably over a hundred million porcelain suspension insulators in service today in the United States. Some of these have been providing reliable service over the span of many decades. For these reasons, efforts to replace the porcelain with other materials has so far been significantly unsuccessful.

Voltages and mechanical loads on insulators are increasing as the trends toward higher voltages, use of large conductors, multiple conductors and longer spans continue. These factors bring increasing need for higher reliability in materials and components for use in transmission lines. The need for an even better suspension insulator to meet these requirements becomes readily apparent. These needs can be defined in terms of practical design consideration.

1. A lighter but stronger insulator would facilitate construction and hot line maintenance.

2. An insulator with a much higher resistance to impact would reduce the susceptibility to breakage during handling and erection, and also would reduce outages caused by rifle fire and other accidental and malicious impacts during normal operation.

3. Puncture proof insulators, with the ability to sustain power arc follow currents without damage, would reduce outages due to lightning and switching surges, and would eliminate dropped lines caused by puncture induced explosion forces.

Early in 1954, a program was initiated by the General Electric Company to find an insulating material for use in outdoor insulators which would provide maximum reliability consistent with the utility industry's future requirements. Literally hundreds of formulations were investigated and tested. Finally, in 1957, a modified epoxy type polymer which appeared to meet our requirements for outdoor service was developed.

To fully explore the possibilities was a time-consuming process. It involved a great variety of investigations and tests to truly understand the characteristics of this material and to develop means of designing practical insulators with it as a base. When working with any new material for application to the exacting requirements of high voltage insulators, one must put aside preconceived ideas. Many of the design and test criteria presently applied to porcelain insulators are either meaningless or inadequate when applied to materials having entirely different characteristics. Other

factors, such as resistance to solar radiation, to temperatures within the atmospheric range, and the effect of time itself may all of a sudden assume new importance.

One of the very critical new factors was the question of resistance to tracking, which is a shortcoming in many polymeric materials. To resolve this, a new "inclined plane test" was developed by our General Engineering Laboratory to evaluate relative tracking resistance. We believe that through this test we can produce in a few hours tracking conditions equivalent to those which might be expected from 20 years of normal field exposure. When the particular epoxy composition had been modified so as to produce non-tracking characteristics on this test, we were ready to proceed with the experimental manufacture of samples for field tests.

INSULATOR DESIGN AND MANUFACTURE

An insulator was designed for use on 69 kv lines using a polyester-bonded fiber-glass rod as a load-bearing member. The rod was encapsulated in the modified epoxy to provide hoods for obtaining creep distance. The design involved an overall diameter of seven inches, an arcing distance of thirty-one inches and a leakage distance of sixty-four inches. The unit was designed for an ultimate strength rating of 15,000 pounds. This modular unit with nine hoods is essentially equivalent to a string of 5 present suspension insulators in electrical characteristics. A photograph of this unit appears as Figure 1.

INSULATOR TESTS

Although the present standard tests were used as one means of evaluating performance, to gain assurance that the insulator would contribute to higher continuity-of-service levels, special tests were also used to complete the evaluation. Some of the test results are presented here in outline.

Electrical Flashover Tests.

Sixty cycle wet and dry flashover tests and impulse positive and negative flashover tests on 1, 2, and 3 units were made on these insulators in accordance with ASA Standard C-29.1 entitled, "American Standard Test Methods of Electrical Power Insulators". The results of these tests are shown on Figure 2. Curve showing the flashover values versus arcing distance for the polymer insulators are presented together with curves for the rated values of strings of porcelain suspension insulators for comparison.

Time Load Tests

The new insulator has been subjected to time-load tests out-of-doors under a continuous mechanical load of 9,000 pounds for five years with no evidence of deterioration. Periodic electrical tests indicate continuing electrical soundness.

High Impact Tests

This test was made at a rifle range. The insulator was mounted in the vertical position and subjected to .22 calibre long-rifle fire from a distance of about 50 feet. All but direct hits glanced off of the insulator without causing any damage. When direct hits on the core of the insulator were made, the bullets simply flattened and bounced off the insulator leaving a mark where they hit, (Figure 3). Fire from a .45 calibre pistol produced the same results, (Figure 4).

The insulator was also subjected to 30/30 calibre M-1 service rifle fire from 50 feet. The bullets damaged skirts and tore parts of the polymer casing from the fiber-

glass core. When the exposed fiberglass core was directly struck by 30/30 rifle fire, some fiberglass breakage took place, but the rod was not completely destroyed and would still support load, (Figure 5). Subsequent M.& E. tests confirmed a capability of at least 20,100 pounds with a hardware failure.

High Current Tests

A shortened section of an insulator was subjected to power arcs of 6500 amperes for five cycles, and a second section to 8500 amperes for four cycles. The arc was initiated by a fuse wire which vaporized over the surface of the insulator in each case. There was no evidence of any burning of the polymer or erosion of the surface anywhere on the insulator.

A porcelain insulator was subjected to a power arc of 7000 amperes for four cycles. The heat from the arc blistered the glazed surface of the insulator. These tests were performed by the Baltimore Gas and Electric Company for the General Electric Company.

Service Tests

With the cooperation of The Baltimore Gas and Electric Company, The Florida Power and Light Company, and The New England Electric System, field test installations using these polymer insulators were established at three locations. Approximately eighteen units were installed on the power lines of each of these companies.

	Date Installed	Operating Voltage
Baltimore Gas & Electric Co. (Figure 6) (Figure 7)	March 1959	115 kv
Florida Power & Light Co. (Figure 8) (Figure 9)	April 1959	69 kv
New England Electric System (Figure 10) (Figure 11)	Oct. 1959	69 kv

These were selected for test areas since they provided many quite varied operating conditions. The New England area is in the so called "Sleet Belt" where winter conditions including snow, wind, and temperature changes are very severe. In Florida, the insulators are on a line adjacent to the Atlantic Ocean at Juno Beach where there is considerable salt contamination along with high ultra-violet radiation.

The salt contamination experience on the Juno Beach line is such that regular insulators are washed on an average of six to eight times per year. The polymer insulators were washed along with the porcelain insulators on the line, but the operators report that during the dry seasons there has been considerably less corona activity noted on the polymer insulators than on the porcelain units. A Baltimore area was selected where frequent observations under actual operating conditions could conveniently be made, and where a wide range of ambient temperatures are common.

The insulators have been carefully observed since their installation. They have operated with no difficulty. In 1962, several were returned from Juno Beach for study by the Insulator Department. There had been no deterioration during this service period. The remaining insulators are still in service. Continual observations of the Baltimore installation indicate no deterioration to date.

A fourth test location is at Pittsfield, Mass. on the test line of the General Electric Company Project EHV. Five of these insulators were installed in series supporting a jumper loop. The installation was made in September, 1961 (Figure 12). The EHV test line was energized in January, 1962, and has been energized at 500 kv to 525 kv for about half of the time since that date. It is reported that no difficulties have been encountered, and that the insulators have performed perfectly in this test area. They are still in service.

DESIGN REVISIONS

Based on the information gained from laboratory investigations, the mechanical design of the original polymer suspension insulators was modified during 1962 and features were incorporated to improve the insulator. The new insulators, now in limited production on a pilot shop basis, are made so that the fiberglass becomes the direct load-bearing member without requiring any transmission of load thru cemented joints. The new units also employ epoxy-bonded fiberglass load-bearing members instead of the polyester-bonded rods. This has the advantage of minimizing the number of interfaces between materials having different coefficients of thermal expansion.

Units of this type can be made to conform to a wide range of ultimate strengths. They display no evidence of elongation creep under load within the working range. The stress-strain curve for a typical unit carrying load to 15,000 pounds is shown in Figure 13. The actual ultimate strength of this unit was 25,500 pounds.

These units can also be made in virtually any length to realize any required electrical properties. As a practical matter combinations of a few standardized lengths will yield a wide variety of practical insulation levels.

As an example, the characteristics of one of the polymer units is shown in Figure 14 in comparison with those of a seven unit string of 5-3/4 x 10" porcelain units. Note particularly that the polymer insulator weighs only about 30% as much as conventional suspension insulators.

POTENTIAL ADVANTAGES OF POLYMER INSULATORS

The polymer insulators described here are still in an experimental stage. Although many laboratory tests have been made we know of no accelerated life test which can, without qualification, predict actual life. This is particularly true when dealing with new materials, and with devices whose life expectancy, without maintenance, must be many years. Results so far at the three field installations, with actual exposure time of about four years, add substantial confidence, but even this information is small both in time and in quantity. A higher confidence level can be gained only by vastly increased practical operating exposure. The potential advantages appear to be well worth these risks, and may be briefly summarized as follows:

1. Approximately 70% weight reduction-reducing construction costs and handling expense.
2. Extremely high mechanical impact strength-reducing breakage in construction and that due to vandalism.
3. High thermal shock resistance-reducing damage from power flashover.
4. Virtually a puncture proof insulator--eliminating line drops from exploded caps.
5. Flexibility of design to permit a wide range of strength requirements.
6. Greatly reduced risk of insulator breakage due to hardware corrosion.
7. A very positive supporting structure without reliance on cemented joints.
8. Excellent R.I.V. performance.
9) Minimizes the number of loose or flexible parts to be handled in construction.
10) Surface washes easily and gives promise of improved performance in contaminated atmospheres.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the assistance rendered by the following utilities in providing test sites and making the necessary installations and observations:

The Baltimore Gas & Electric Co.
The Florida Power and Light Co.
The New England Electric System.

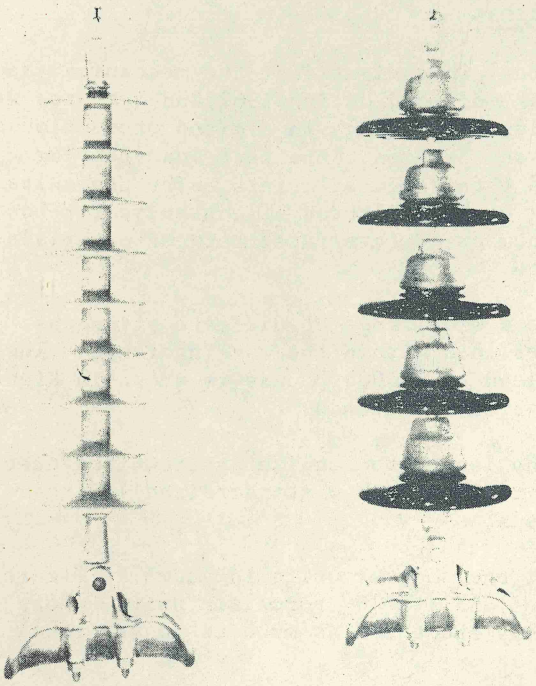

Fig. 1. Polymer Insulator compared with a string of five suspension insulators 10" in diameter, 5-3/4" spaced.

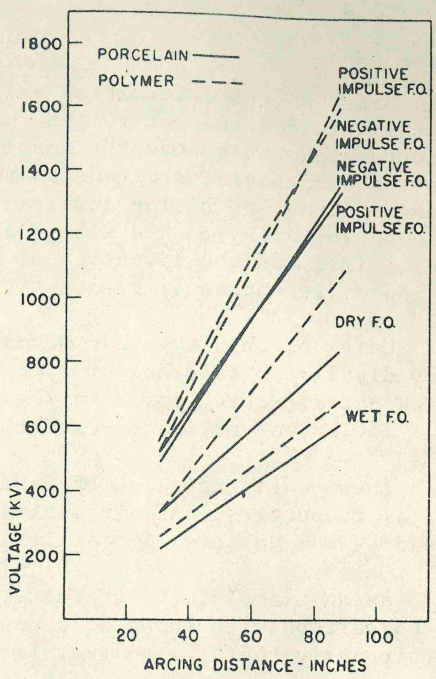

Fig. 2. A comparison of the electrical characteristics of Polymer Insulators with rated values of porcelain suspension insulators 10" in diameter 5-3/4" spaced.

Fig. 3. Polymer Insulator after receiving direct hits from .22 calibre long rifle fire at 50 feet.

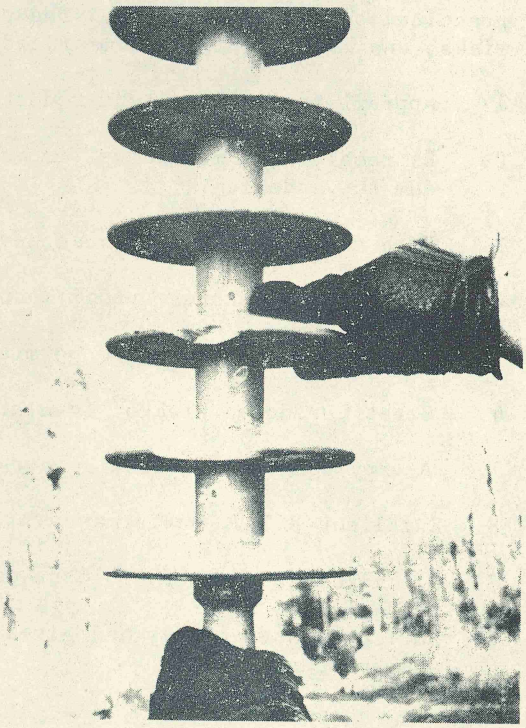

Fig. 4. Polymer Insulator after being subjected to direct hit from a .45 calibre service pistol.

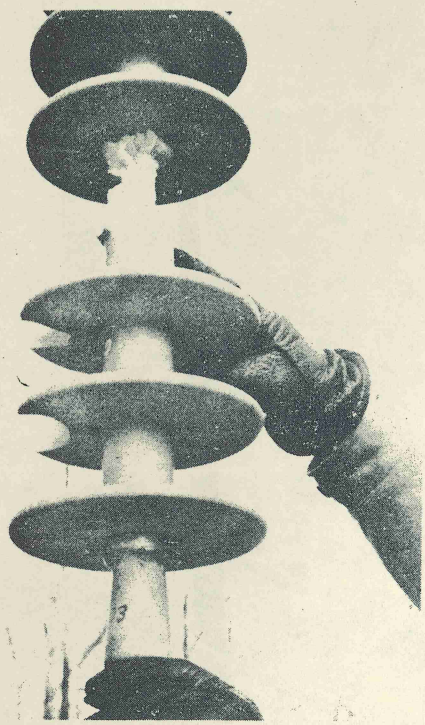

Fig. 5. Polymer Insulator after being hit with many rounds from a 30/30 calibre M-1 service rifle.

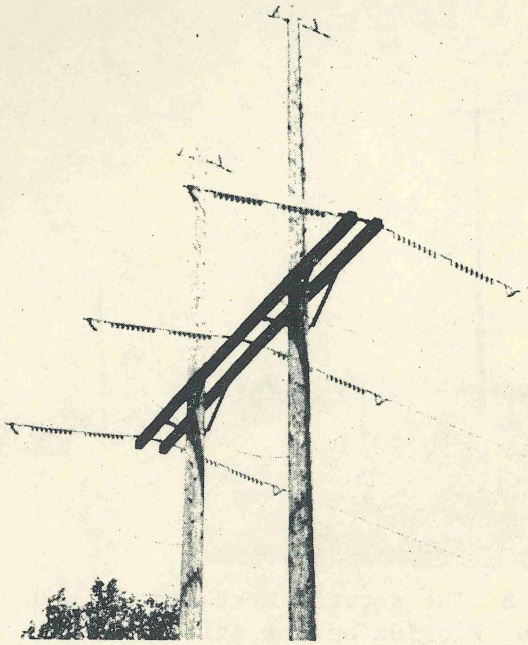

Fig. 6. Polymer Insulators installed on a 115 kv line of The Baltimore Gas & Electric Company.

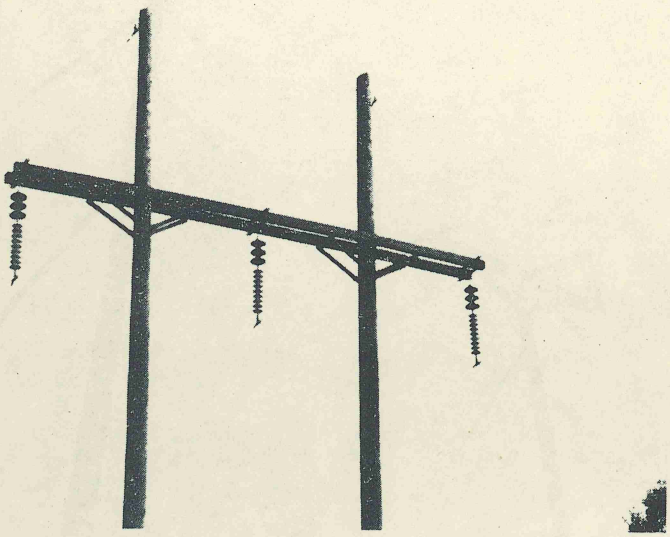

Fig. 7. Polymer Insulators in series with standard porcelain suspension insulators on a 115 kv line of The Baltimore Gas and Electric Company.

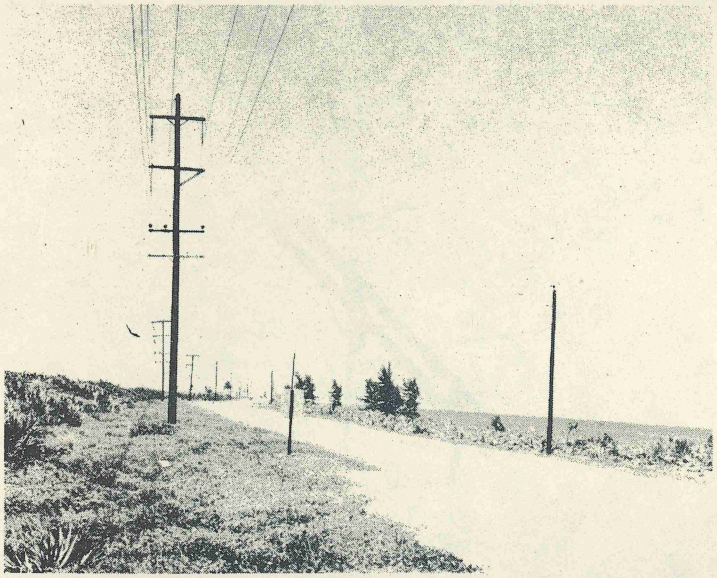

Fig. 8. The service test area at Juno Beach, Florida on the Atlantic Coast serviced by The Florida Power & Light Company.

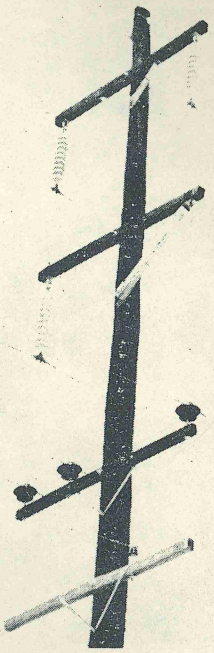

Fig. 9. Polymer Insulators in service on a 69 kv line of The Florida Power & Light Company at Juno Beach, Florida.

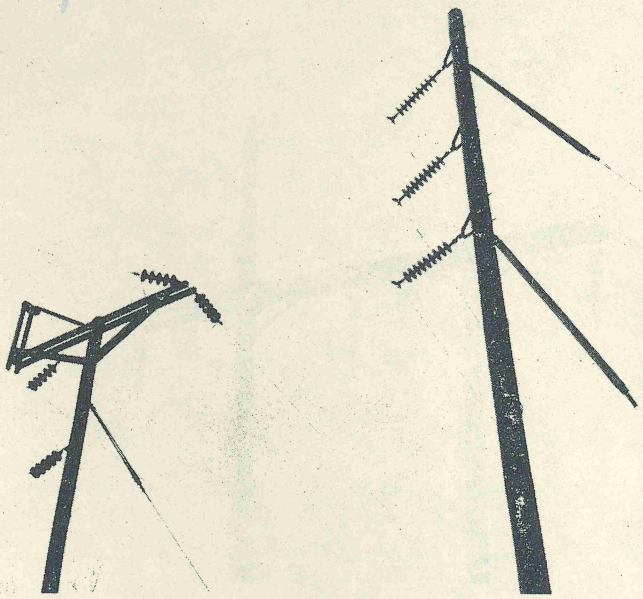

Fig. 10. Polymer Insulators in service on a 69 kv line of The New England Electric System.

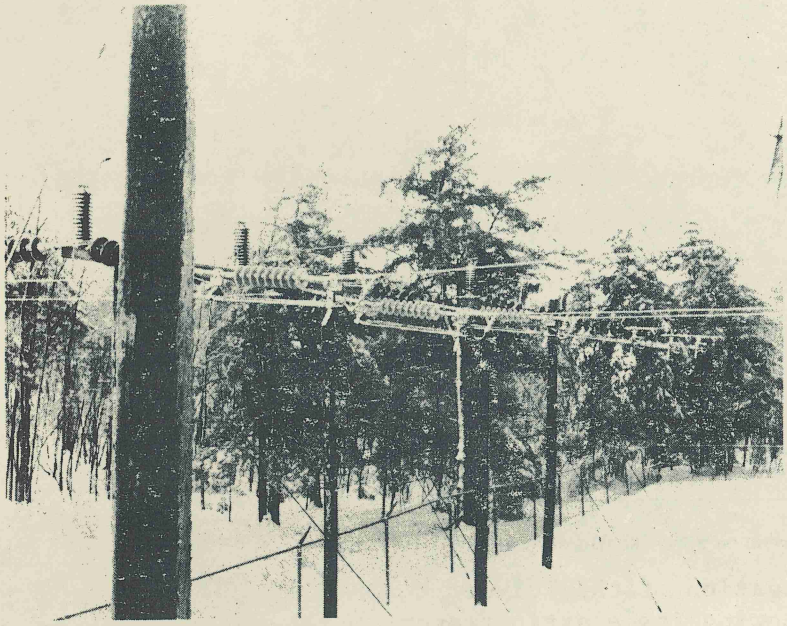

Fig. 11. A special application of Polymer Insulators on a 69 kv line of The New England Electric System.

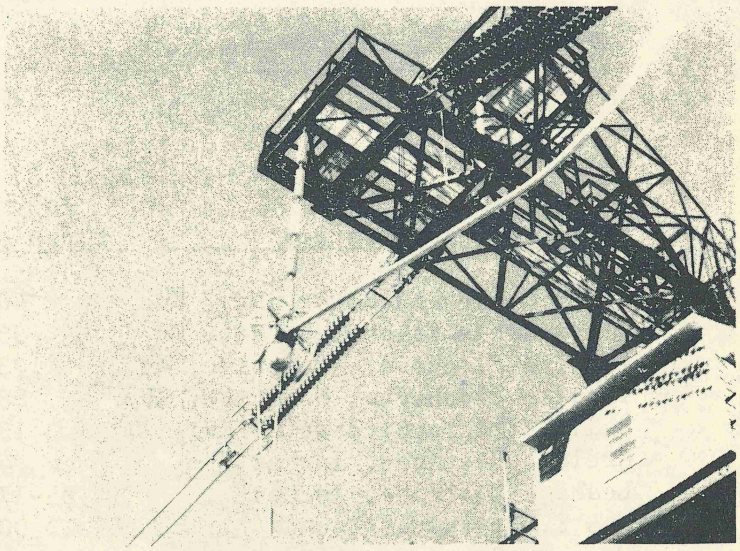

Fig. 12. Polymer Insulators on the General Electric Company EHV Line in Pittsfield, Mass.

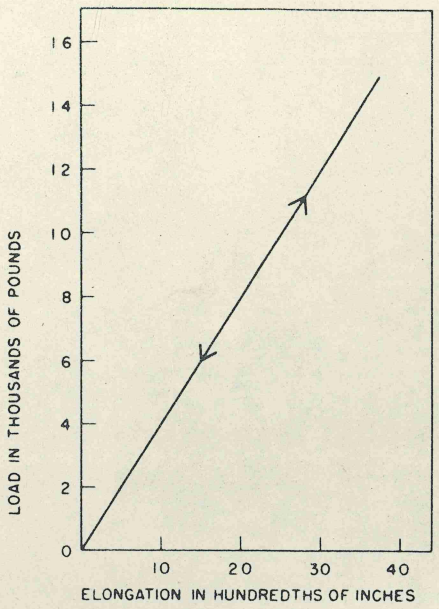

Fig. 13. Elogation of the Polymer Insulator showing its elastic properties.

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Arcing Distance, Inches	43	41-1/2
Leakage Distance, Inches	85-1/4	80-1/2
M.& E. Strength, Pounds	22,000	15,000
Weight, Pounds	22	77

Fig. 14. Comparison of the characteristics of a redesigned Polymer Insulator with a string of 7 porcelain insulators 10" in diameter, 5-3/4" spaced.

Conference Paper

A POLYMER INSULATOR FOR HIGH VOLTAGE TRANSMISSION LINES

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INTRODUCTION

Wet process electrical porcelain has been used in all types of suspension insulators for many years. Its long life, high dielectric strength, imperviousness to most chemicals, resistance to electrical tracking, and low materials cost have retained for porcelain a unique position as the insulating element in suspension insulators. There are probably over a hundred million porcelain suspension insulators in service today in the United States. Some of these have been providing reliable service over the span of many decades. For these reasons, efforts to replace the porcelain with other materials has so far been significantly unsuccessful.

Voltages and mechanical loads on insulators are increasing as the trends toward higher voltages, use of large conductors, multiple conductors and longer spans continue. These factors bring increasing need for higher reliability in materials and components for use in transmission lines. The need for an even better suspension insulator to meet these requirements becomes readily apparent. These needs can be defined in terms of practical design consideration.

1. A lighter but stronger insulator would facilitate construction and hot line maintenance.

2. An insulator with a much higher resistance to impact would reduce the susceptibility to breakage during handling and erection, and also would reduce outages caused by rifle fire and other accidental and malicious impacts during normal operation.

3. Puncture proof insulators, with the ability to sustain power arc follow currents without damage, would reduce outages due to lightning and switching surges, and would eliminate dropped lines caused by puncture induced explosion forces.

Early in 1954, a program was initiated by the General Electric Company to find an insulating material for use in outdoor insulators which would provide maximum reliability consistent with the utility industry's future requirements. Literally hundreds of formulations were investigated and tested. Finally, in 1957, a modified epoxy type polymer which appeared to meet our requirements for outdoor service was developed.

To fully explore the possibilities was a time-consuming process. It involved a great variety of investigations and tests to truly understand the characteristics of this material and to develop means of designing practical insulators with it as a base. When working with any new material for application to the exacting requirements of high voltage insulators, one must put aside preconceived ideas. Many of the design and test criteria presently applied to porcelain insulators are either meaningless or inadequate when applied to materials having entirely different characteristics. Other

factors, such as resistance to solar radiation, to temperatures within the atmospheric range, and the effect of time itself may all of a sudden assume new importance.

One of the very critical new factors was the question of resistance to tracking, which is a shortcoming in many polymeric materials. To resolve this, a new "inclined plane test" was developed by our General Engineering Laboratory to evaluate relative tracking resistance. We believe that through this test we can produce in a few hours tracking conditions equivalent to those which might be expected from 20 years of normal field exposure. When the particular epoxy composition had been modified so as to produce non-tracking characteristics on this test, we were ready to proceed with the experimental manufacture of samples for field tests.

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Although the present standard tests were used as one means of evaluating performance, to gain assurance that the insulator would contribute to higher continuity-of-service levels, special tests were also used to complete the evaluation. Some of the test results are presented here in outline.

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glass core. When the exposed fiberglass core was directly struck by 30/30 rifle fire, some fiberglass breakage took place, but the rod was not completely destroyed and would still support load, (Figure 5). Subsequent M.& E. tests confirmed a capability of at least 20,100 pounds with a hardware failure.

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These were selected for test areas since they provided many quite varied operating conditions. The New England area is in the so called "Sleet Belt" where winter conditions including snow, wind, and temperature changes are very severe. In Florida, the insulators are on a line adjacent to the Atlantic Ocean at Juno Beach where there is considerable salt contamination along with high ultra-violet radiation.

The salt contamination experience on the Juno Beach line is such that regular insulators are washed on an average of six to eight times per year. The polymer insulators were washed along with the porcelain insulators on the line, but the operators report that during the dry seasons there has been considerably less corona activity noted on the polymer insulators than on the porcelain units. A Baltimore area was selected where frequent observations under actual operating conditions could conveniently be made, and where a wide range of ambient temperatures are common.

The insulators have been carefully observed since their installation. They have operated with no difficulty. In 1962, several were returned from Juno Beach for study by the Insulator Department. There had been no deterioration during this service period. The remaining insulators are still in service. Continual observations of the Baltimore installation indicate no deterioration to date.

A fourth test location is at Pittsfield, Mass. on the test line of the General Electric Company Project EHV. Five of these insulators were installed in series supporting a jumper loop. The installation was made in September, 1961 (Figure 12). The EHV test line was energized in January, 1962, and has been energized at 500 kv to 525 kv for about half of the time since that date. It is reported that no difficulties have been encountered, and that the insulators have performed perfectly in this test area. They are still in service.

DESIGN REVISIONS

Based on the information gained from laboratory investigations, the mechanical design of the original polymer suspension insulators was modified during 1962 and features were incorporated to improve the insulator. The new insulators, now in limited production on a pilot shop basis, are made so that the fiberglass becomes the direct load-bearing member without requiring any transmission of load thru cemented joints. The new units also employ epoxy-bonded fiberglass load-bearing members instead of the polyester-bonded rods. This has the advantage of minimizing the number of interfaces between materials having different coefficients of thermal expansion.

Units of this type can be made to conform to a wide range of ultimate strengths. They display no evidence of elongation creep under load within the working range. The stress-strain curve for a typical unit carrying load to 15,000 pounds is shown in Figure 13. The actual ultimate strength of this unit was 25,500 pounds.

These units can also be made in virtually any length to realize any required electrical properties. As a practical matter combinations of a few standardized lengths will yield a wide variety of practical insulation levels.

As an example, the characteristics of one of the polymer units is shown in Figure 14 in comparison with those of a seven unit string of 5-3/4 x 10" porcelain units. Note particularly that the polymer insulator weighs only about 30% as much as conventional suspension insulators.

POTENTIAL ADVANTAGES OF POLYMER INSULATORS

The polymer insulators described here are still in an experimental stage. Although many laboratory tests have been made we know of no accelerated life test which can, without qualification, predict actual life. This is particularly true when dealing with new materials, and with devices whose life expectancy, without maintenance, must be many years. Results so far at the three field installations, with actual exposure time of about four years, add substantial confidence, but even this information is small both in time and in quantity. A higher confidence level can be gained only by vastly increased practical operating exposure. The potential advantages appear to be well worth these risks, and may be briefly summarized as follows:

1. Approximately 70% weight reduction-reducing construction costs and handling expense.
2. Extremely high mechanical impact strength-reducing breakage in construction and that due to vandalism.
3. High thermal shock resistance-reducing damage from power flashover.
4. Virtually a puncture proof insulator--eliminating line drops from exploded caps.
5. Flexibility of design to permit a wide range of strength requirements.
6. Greatly reduced risk of insulator breakage due to hardware corrosion.
7. A very positive supporting structure without reliance on cemented joints.
8. Excellent R.I.V. performance.
9) Minimizes the number of loose or flexible parts to be handled in construction.
10) Surface washes easily and gives promise of improved performance in contaminated atmospheres.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the assistance rendered by the following utilities in providing test sites and making the necessary installations and observations:

The Baltimore Gas & Electric Co.
The Florida Power and Light Co.
The New England Electric System.

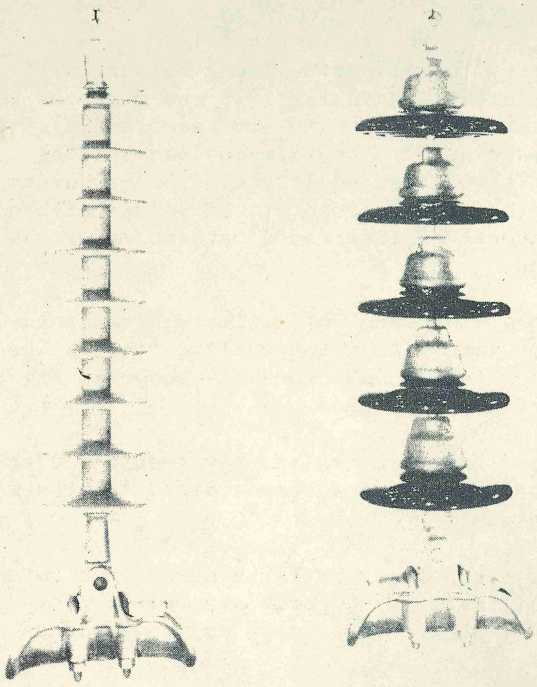


Fig. 1. Polymer Insulator compared with a string of five suspension insulators 10" in diameter, 5-3/4" spaced.

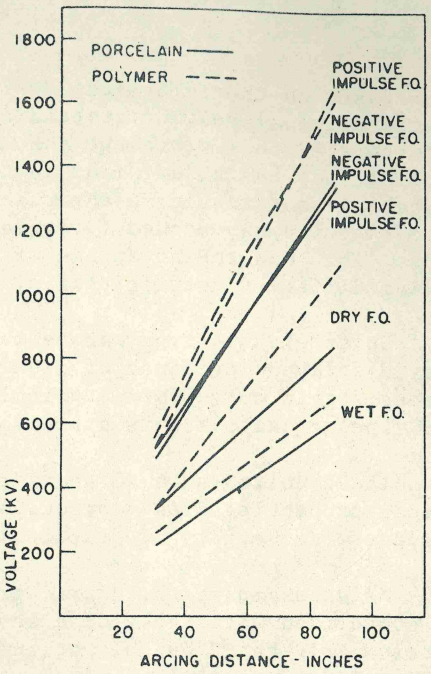


Fig. 2. A comparison of the electrical characteristics of Polymer Insulators with rated values of porcelain suspension insulators 10" in diameter 5-3/4" spaced.

Fig. 3. Polymer Insulator after receiving direct hits from .22 calibre long rifle fire at 50 feet.

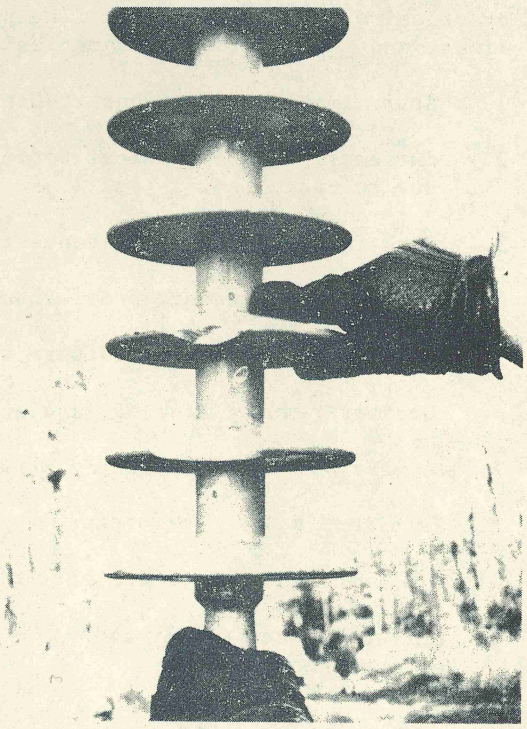


Fig. 4. Polymer Insulator after being subjected to direct hit from a .45 calibre service pistol.

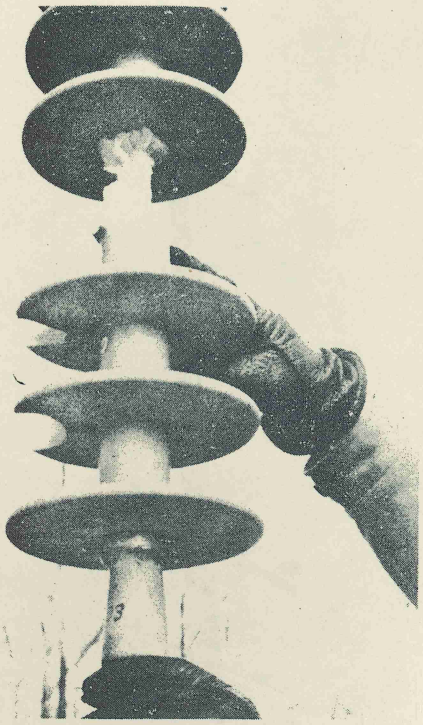


Fig. 5. Polymer Insulator after being hit with many rounds from a 30/30 calibre M-1 service rifle.

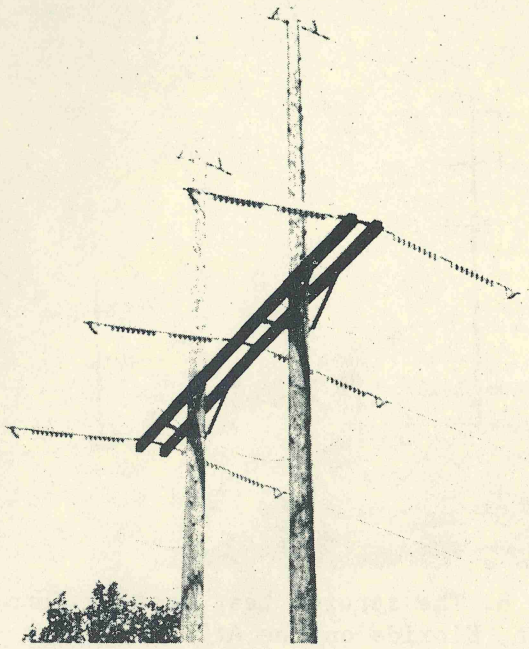


Fig. 6. Polymer Insulators installed on a 115 kv line of The Baltimore Gas & Electric Company.

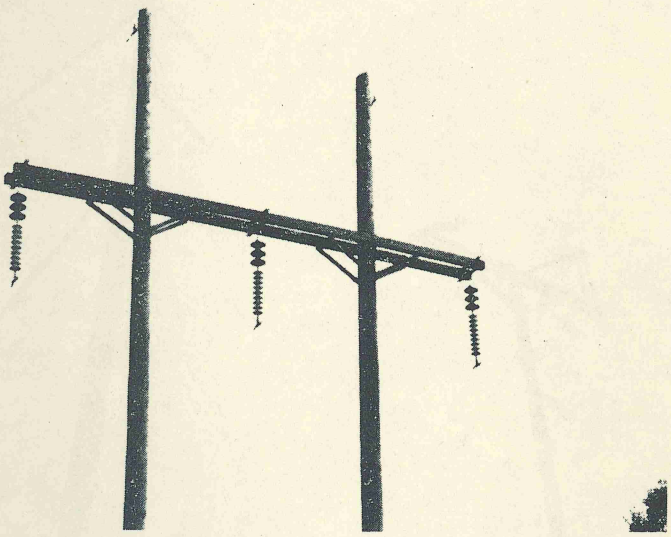


Fig. 7. Polymer Insulators in series with standard porcelain suspension insulators on a 115 kv line of The Baltimore Gas and Electric Company.

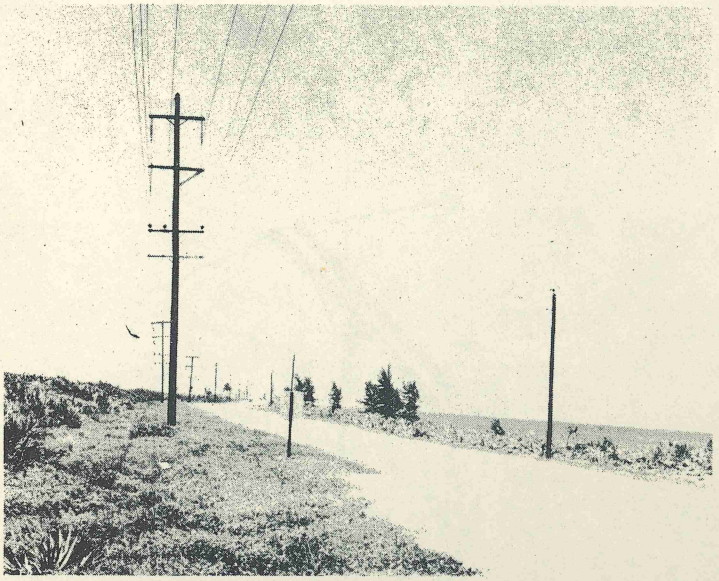


Fig. 8. The service test area at Juno Beach, Florida on the Atlantic Coast serviced by The Florida Power & Light Company.

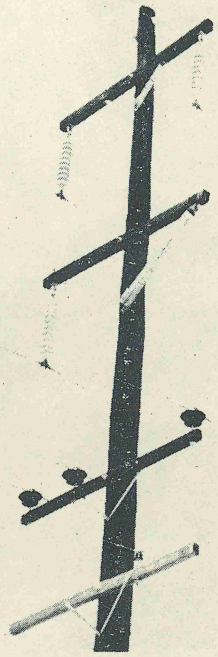
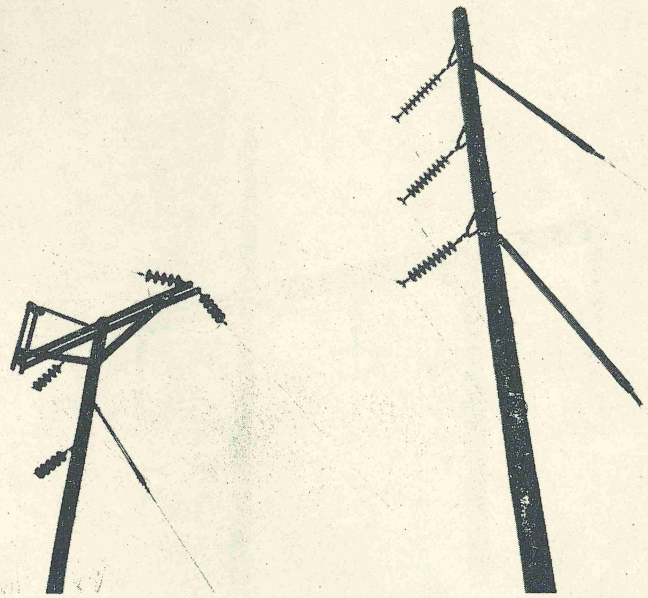


Fig. 9. Polymer Insulators in service on a 69 kv line of The Florida Power & Light Company at Juno Beach, Florida.



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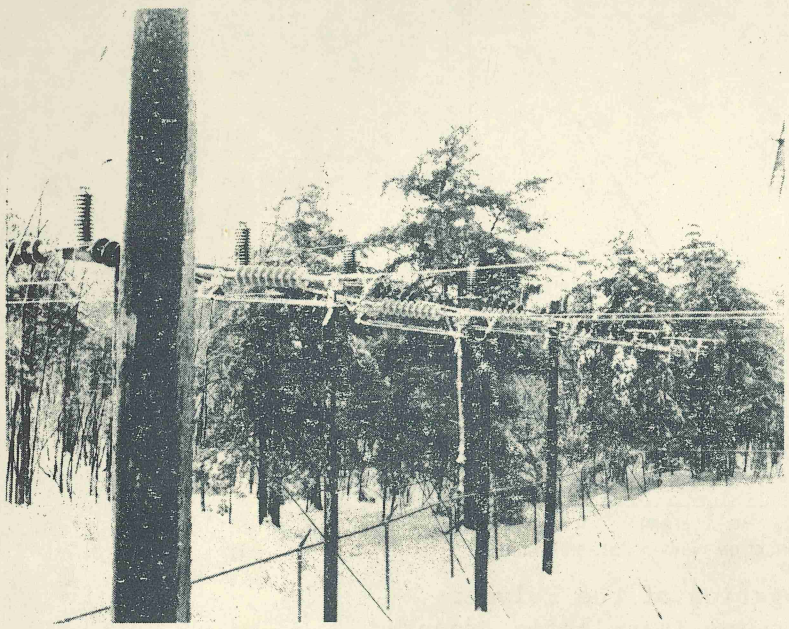

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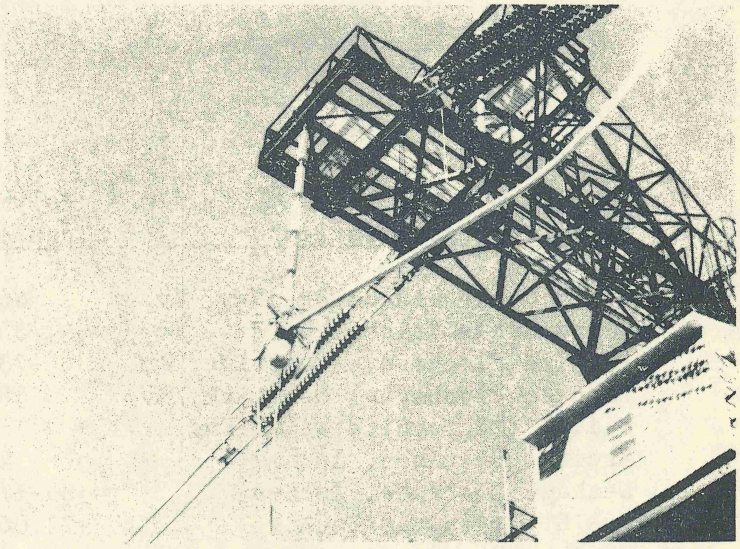
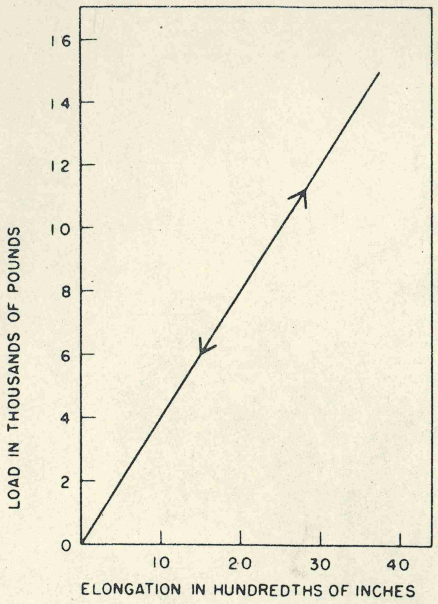


Fig. 12. Polymer Insulators on the General Electric Company EHV Line in Pittsfield, Mass.



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Based on the information gained from laboratory investigations, the mechanical design of the original polymer suspension insulators was modified during 1962 and features were incorporated to improve the insulator. The new insulators, now in limited production on a pilot shop basis, are made so that the fiberglass becomes the direct load-bearing member without requiring any transmission of load thru cemented joints. The new units also employ epoxy-bonded fiberglass load-bearing members instead of the polyester-bonded rods. This has the advantage of minimizing the number of interfaces between materials having different coefficients of thermal expansion.

Units of this type can be made to conform to a wide range of ultimate strengths. They display no evidence of elongation creep under load within the working range. The stress-strain curve for a typical unit carrying load to 15,000 pounds is shown in Figure 13. The actual ultimate strength of this unit was 25,500 pounds.

These units can also be made in virtually any length to realize any required electrical properties. As a practical matter combinations of a few standardized lengths will yield a wide variety of practical insulation levels.

As an example, the characteristics of one of the polymer units is shown in Figure 14 in comparison with those of a seven unit string of 5-3/4 x 10" porcelain units. Note particularly that the polymer insulator weighs only about 30% as much as conventional suspension insulators.

POTENTIAL ADVANTAGES OF POLYMER INSULATORS

The polymer insulators described here are still in an experimental stage. Although many laboratory tests have been made we know of no accelerated life test which can, without qualification, predict actual life. This is particularly true when dealing with new materials, and with devices whose life expectancy, without maintenance, must be many years. Results so far at the three field installations, with actual exposure time of about four years, add substantial confidence, but even this information is small both in time and in quantity. A higher confidence level can be gained only by vastly increased practical operating exposure. The potential advantages appear to be well worth these risks, and may be briefly summarized as follows:

1. Approximately 70% weight reduction-reducing construction costs and handling expense.
2. Extremely high mechanical impact strength-reducing breakage in construction and that due to vandalism.
3. High thermal shock resistance-reducing damage from power flashover.
4. Virtually a puncture proof insulator--eliminating line drops from exploded caps.
5. Flexibility of design to permit a wide range of strength requirements.
6. Greatly reduced risk of insulator breakage due to hardware corrosion.
7. A very positive supporting structure without reliance on cemented joints.

8. Excellent R.I.V. performance.

9) Minimizes the number of loose or flexible parts to be handled in construction.

10) Surface washes easily and gives promise of improved performance in contaminated atmospheres.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the assistance rendered by the following utilities in providing test sites and making the necessary installations and observations:

The Baltimore Gas & Electric Co.
The Florida Power and Light Co.
The New England Electric System.

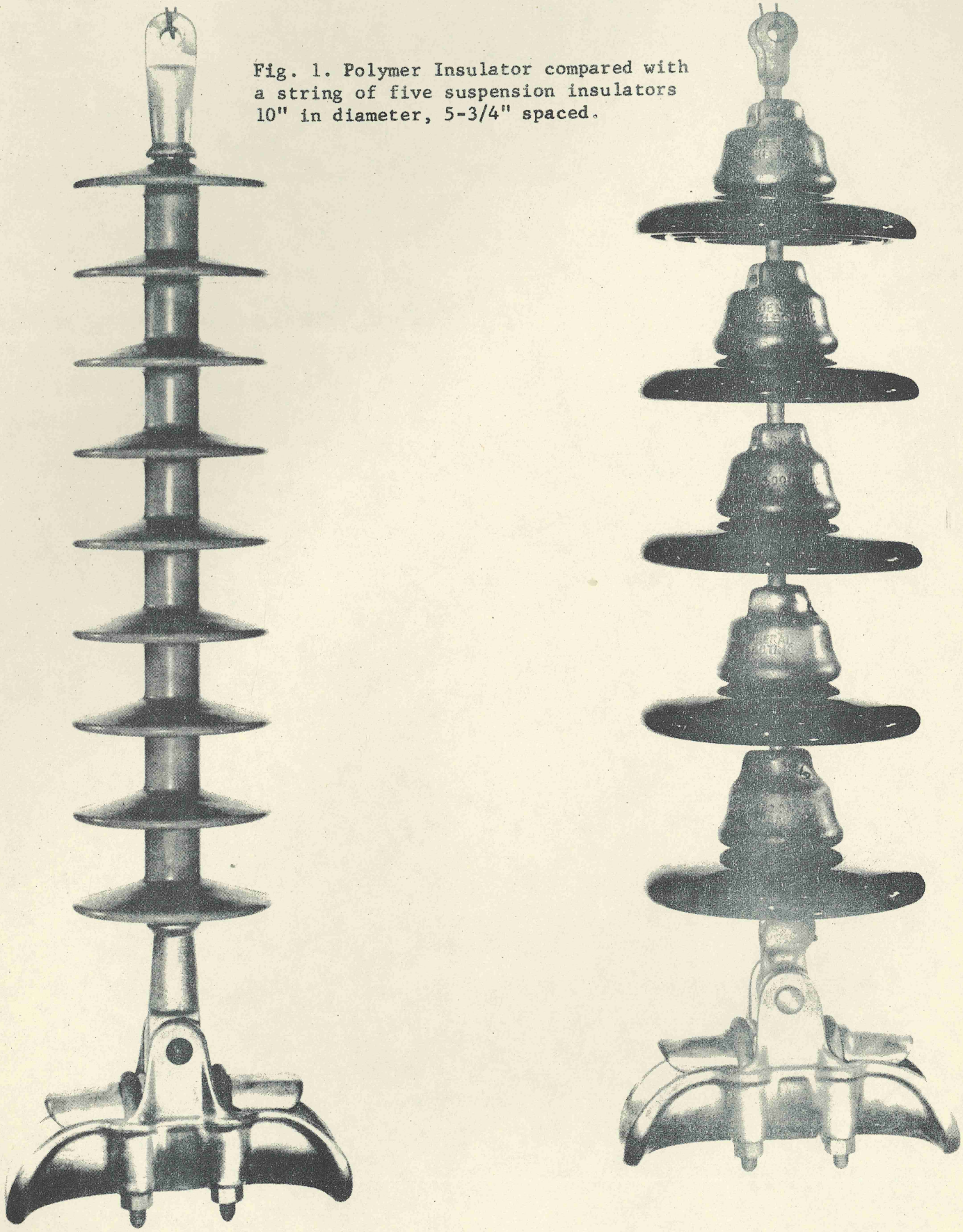


Fig. 1. Polymer Insulator compared with a string of five suspension insulators 10" in diameter, 5-3/4" spaced.

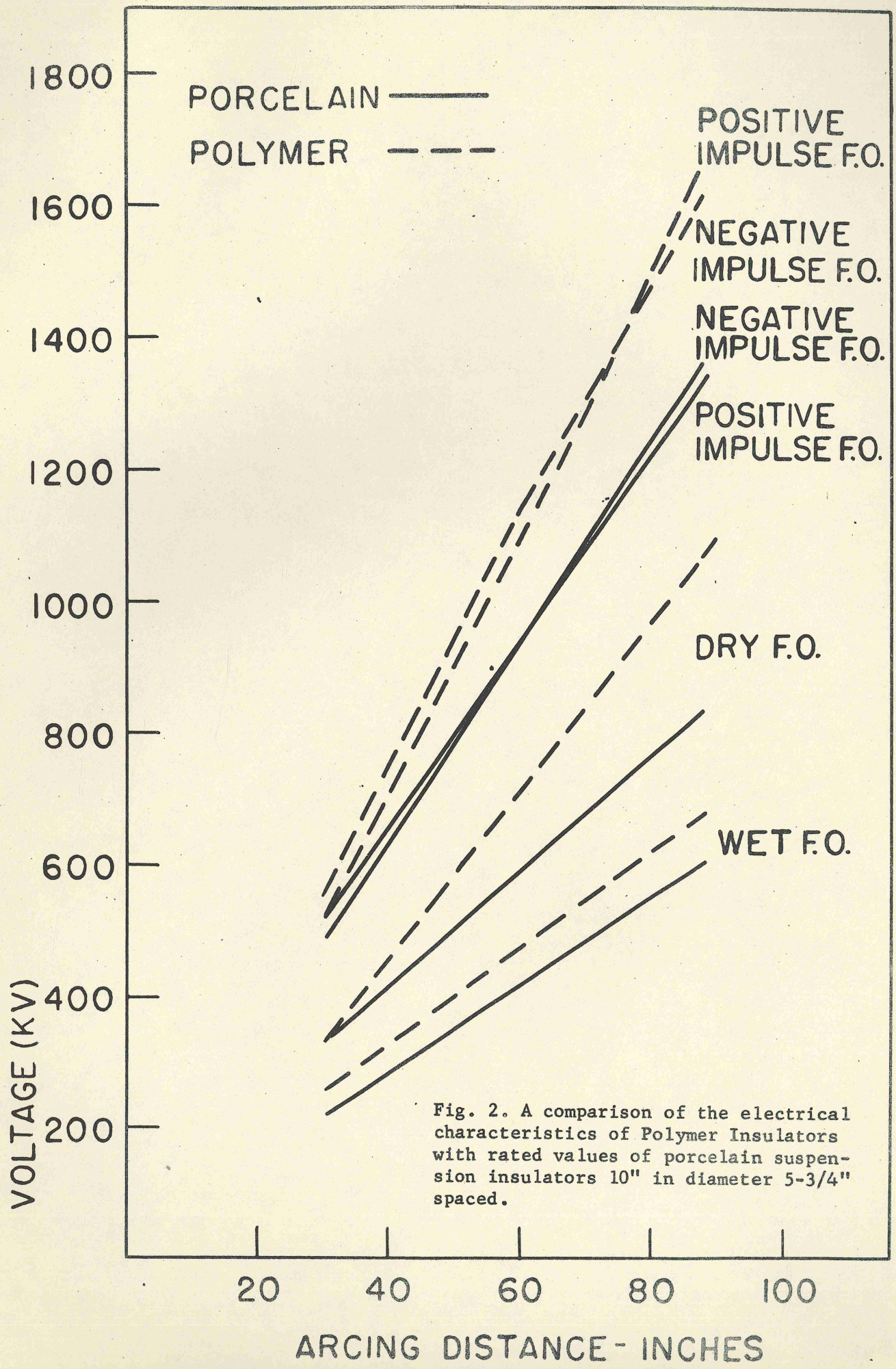


Fig. 2. A comparison of the electrical characteristics of Polymer Insulators with rated values of porcelain suspension insulators 10" in diameter 5-3/4" spaced.

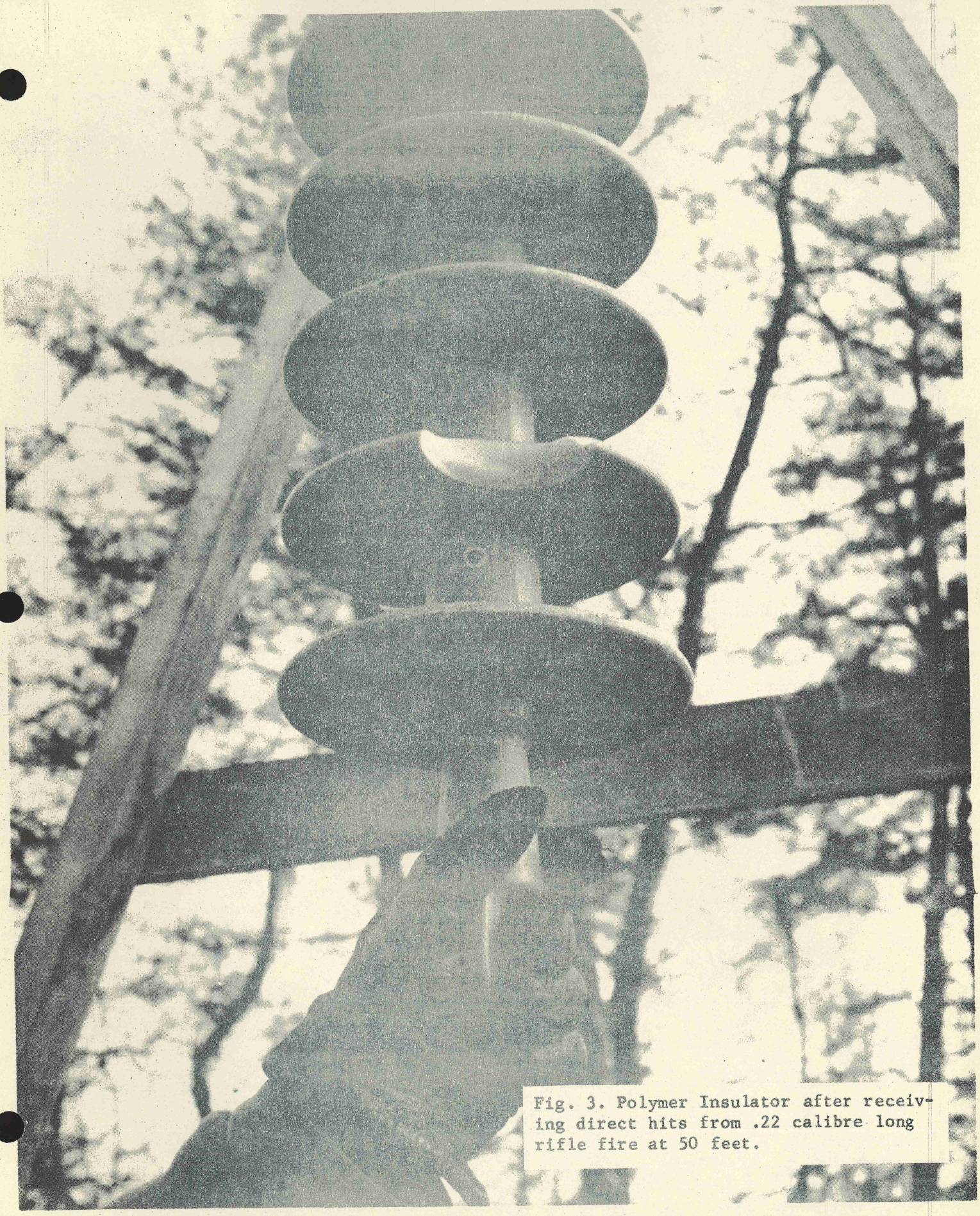


Fig. 3. Polymer Insulator after receiving direct hits from .22 calibre long rifle fire at 50 feet.

Fig. 4. Polymer Insulator after being subjected to direct hit from a .45 calibre service pistol.

Fig. 5. Polymer Insulator after being hit with many rounds from a 30/30 calibre M-1 service rifle.

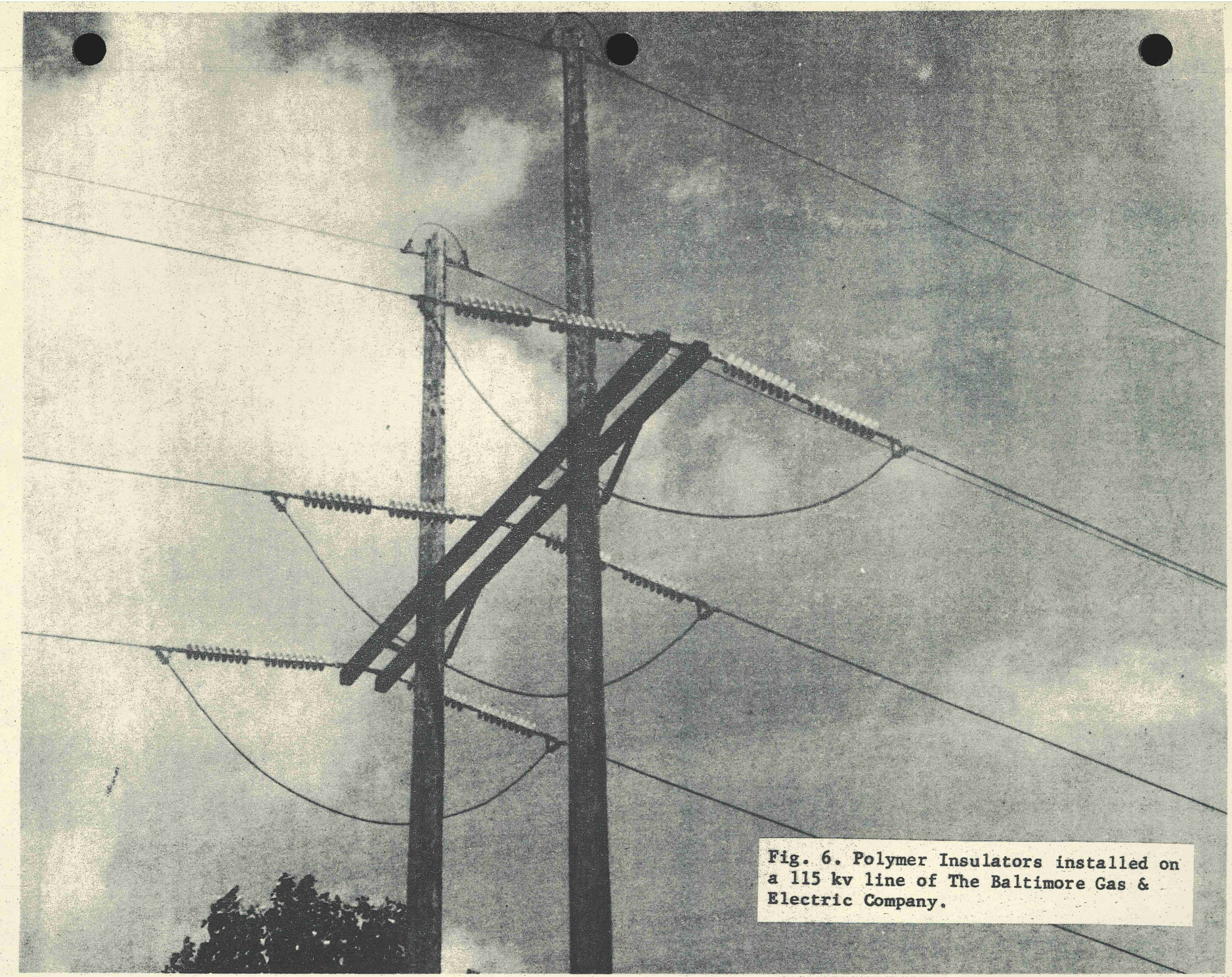


Fig. 6. Polymer Insulators installed on a 115 kv line of The Baltimore Gas & Electric Company.

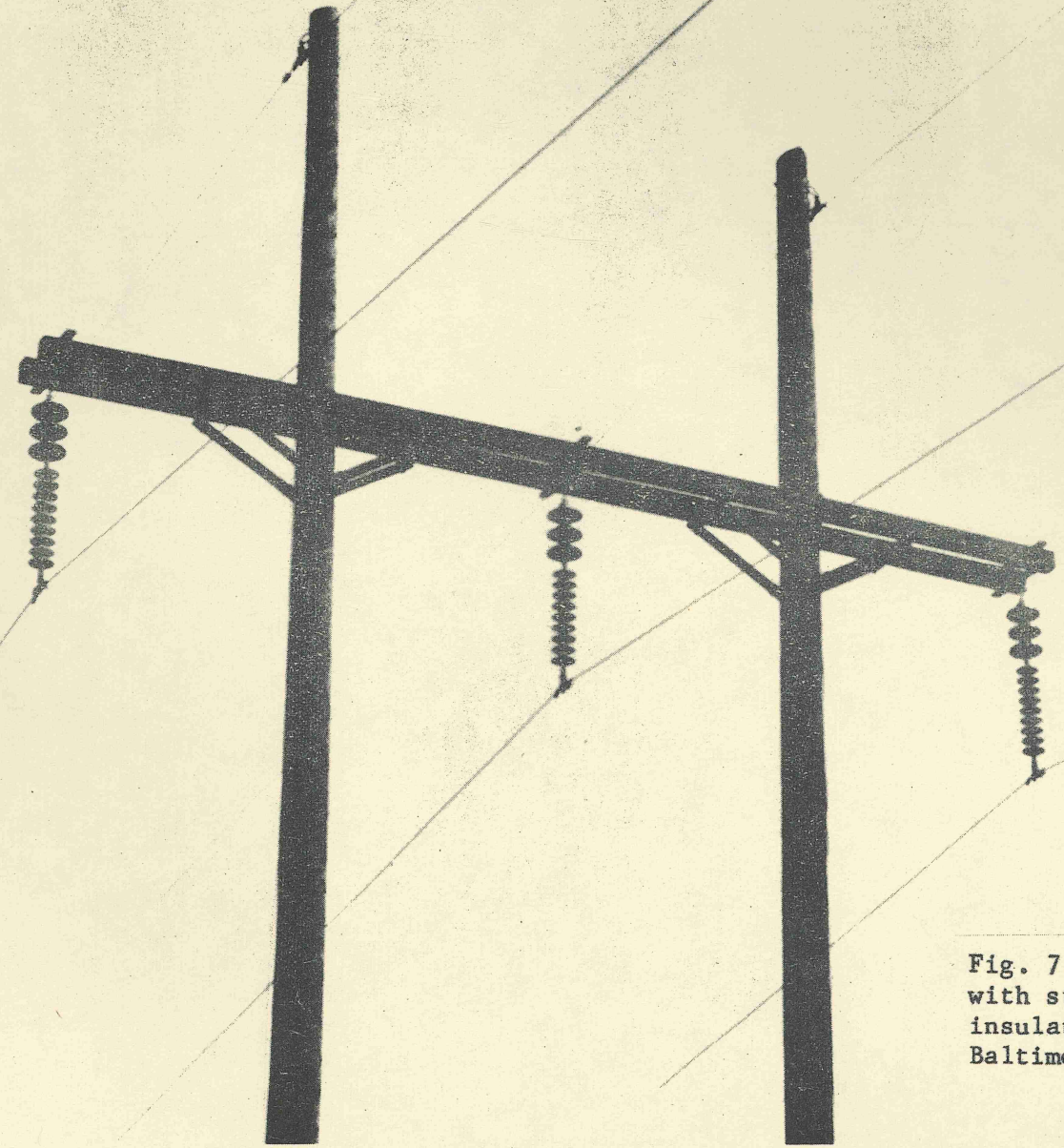


Fig. 7. Polymer Insulators in series with standard porcelain suspension insulators on a 115 kv line of The Baltimore Gas and Electric Company.

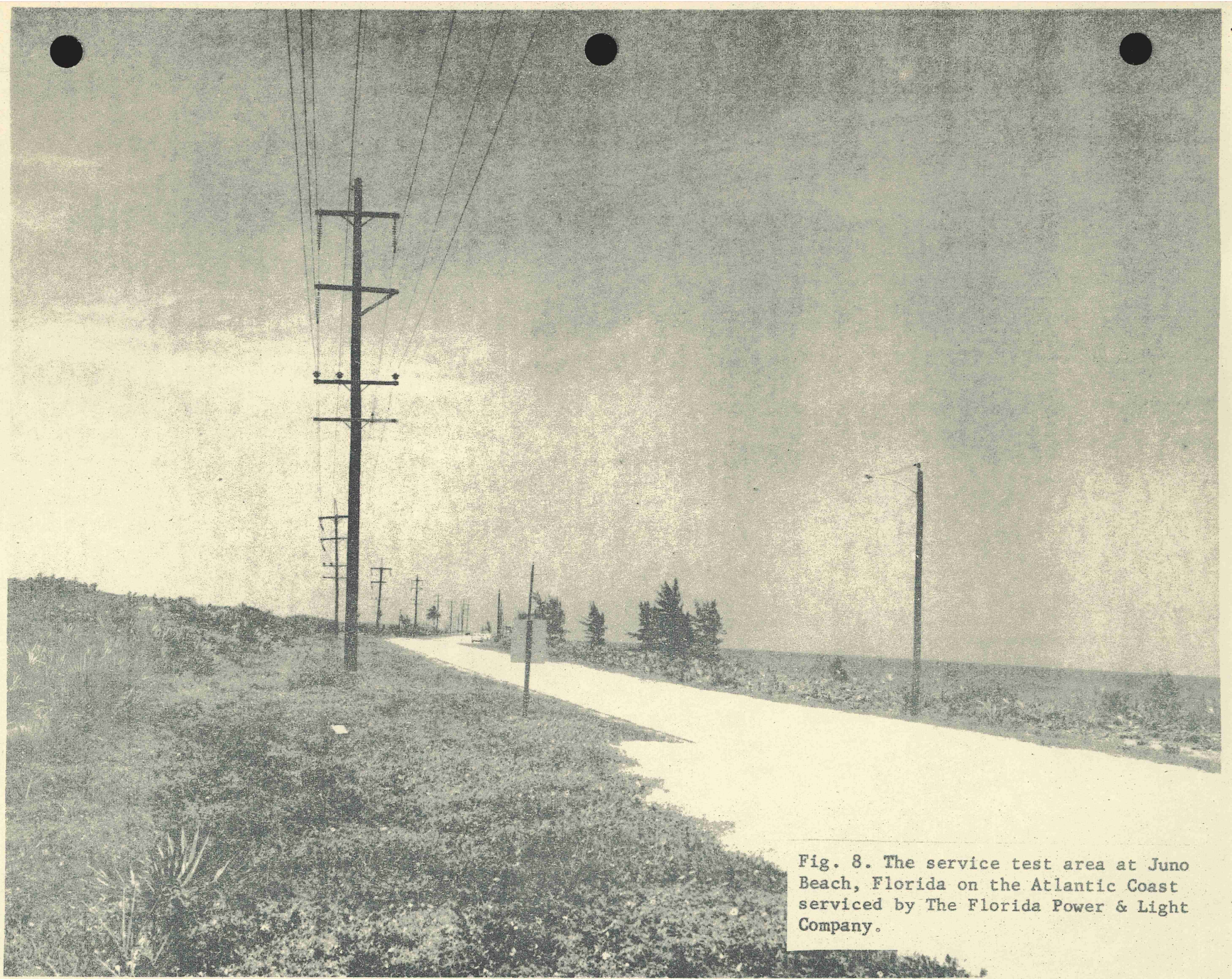


Fig. 8. The service test area at Juno Beach, Florida on the Atlantic Coast serviced by The Florida Power & Light Company.

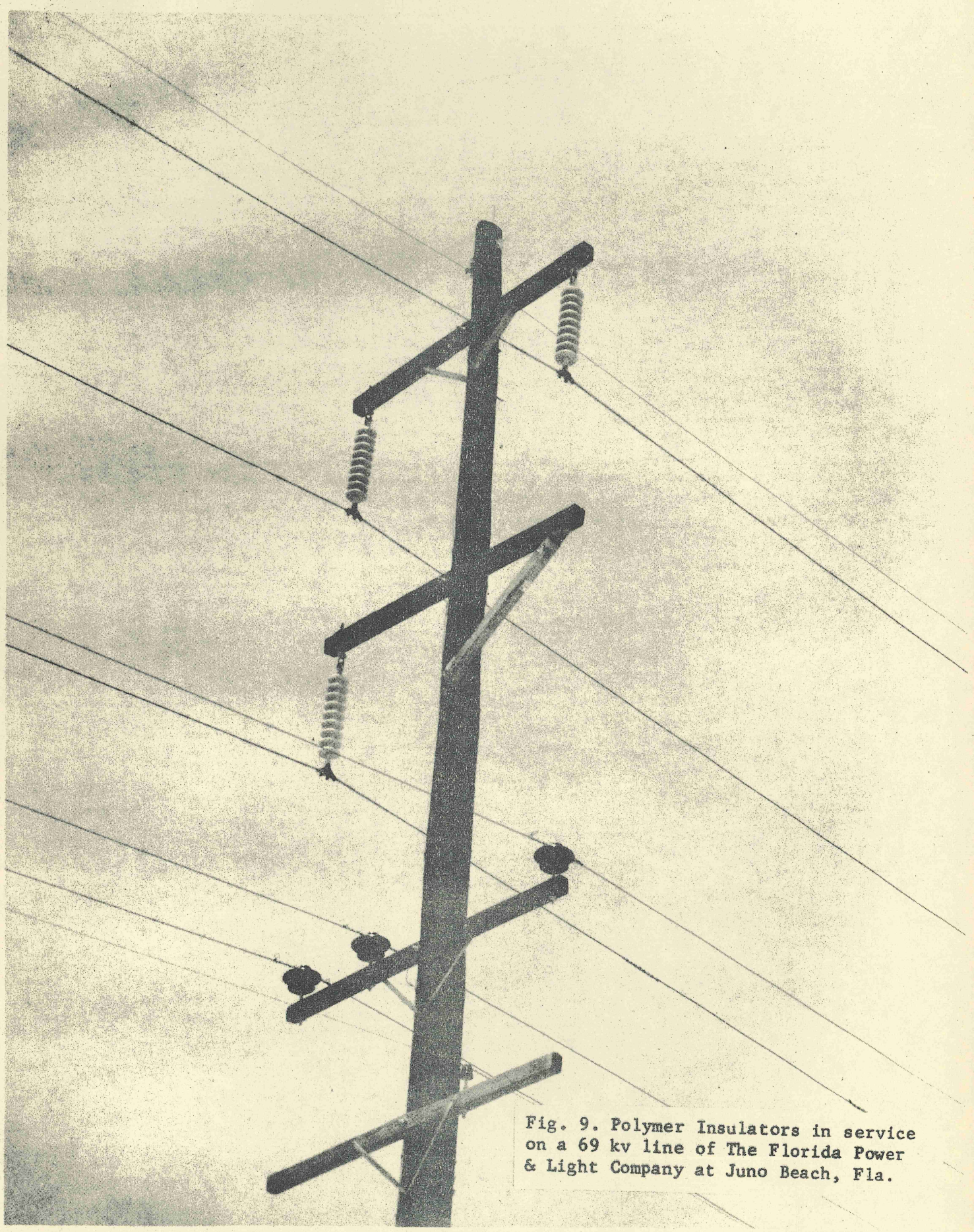


Fig. 9. Polymer Insulators in service on a 69 kv line of The Florida Power & Light Company at Juno Beach, Fla.

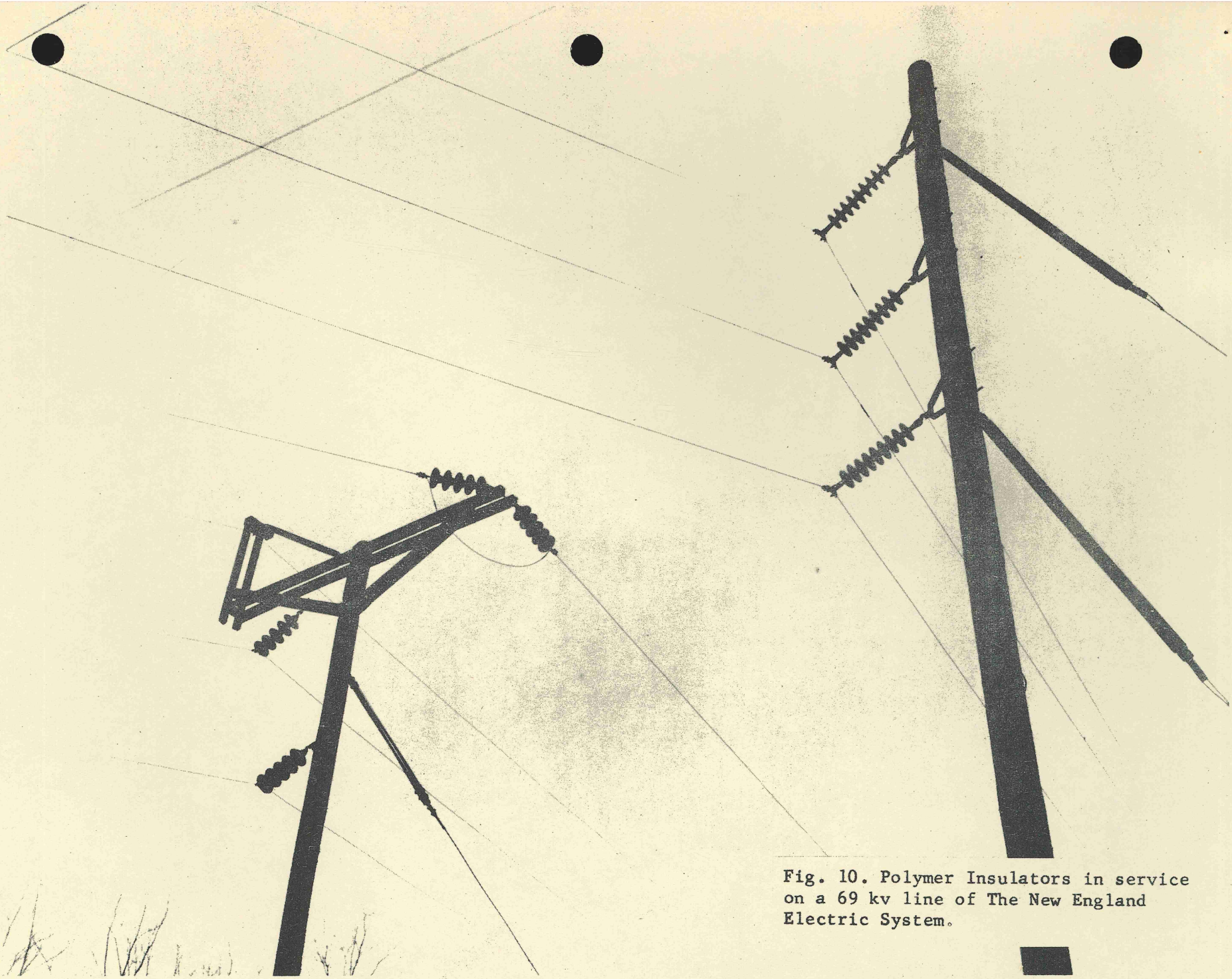


Fig. 10. Polymer Insulators in service on a 69 kv line of The New England Electric System.

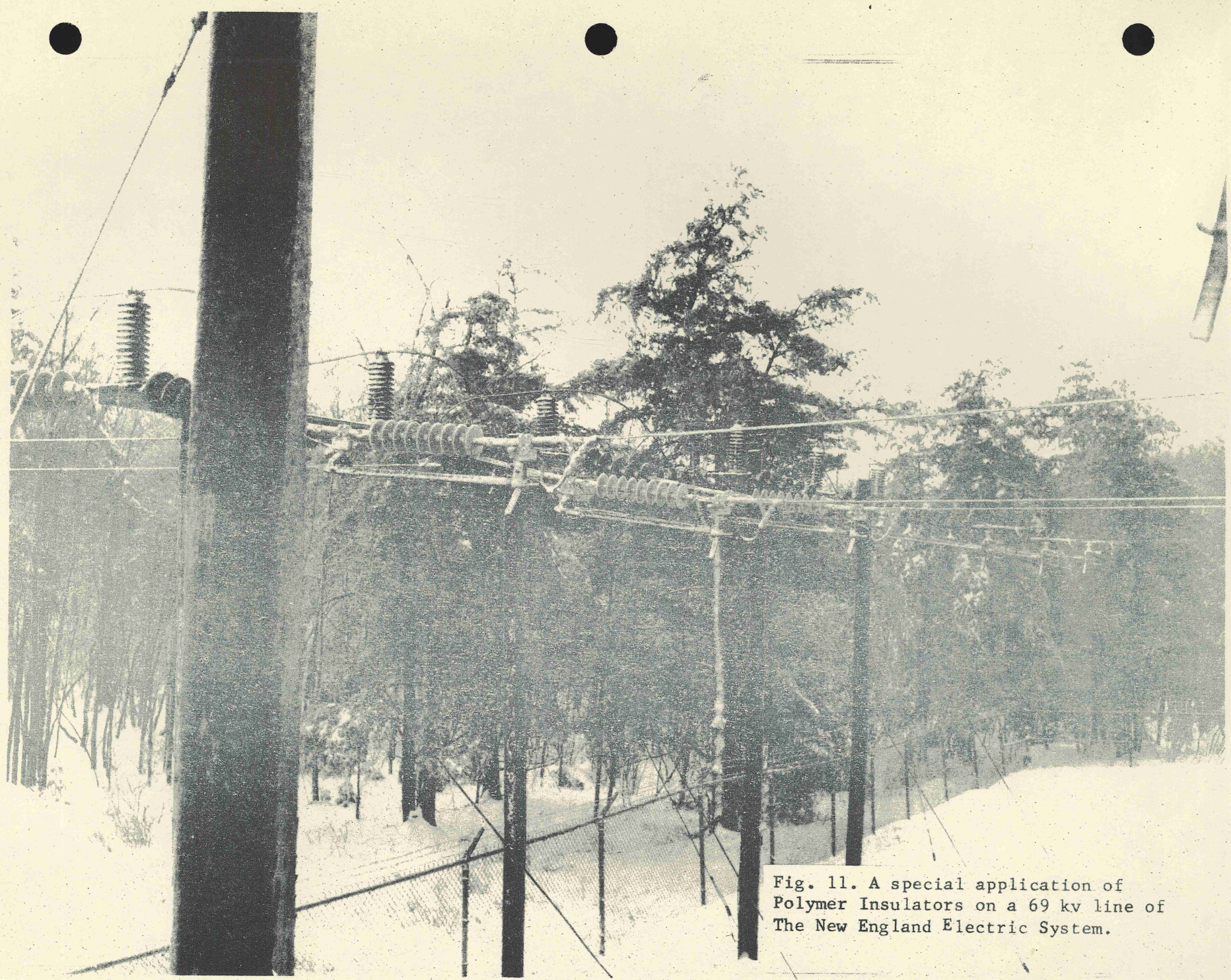


Fig. 11. A special application of Polymer Insulators on a 69 kv line of The New England Electric System.

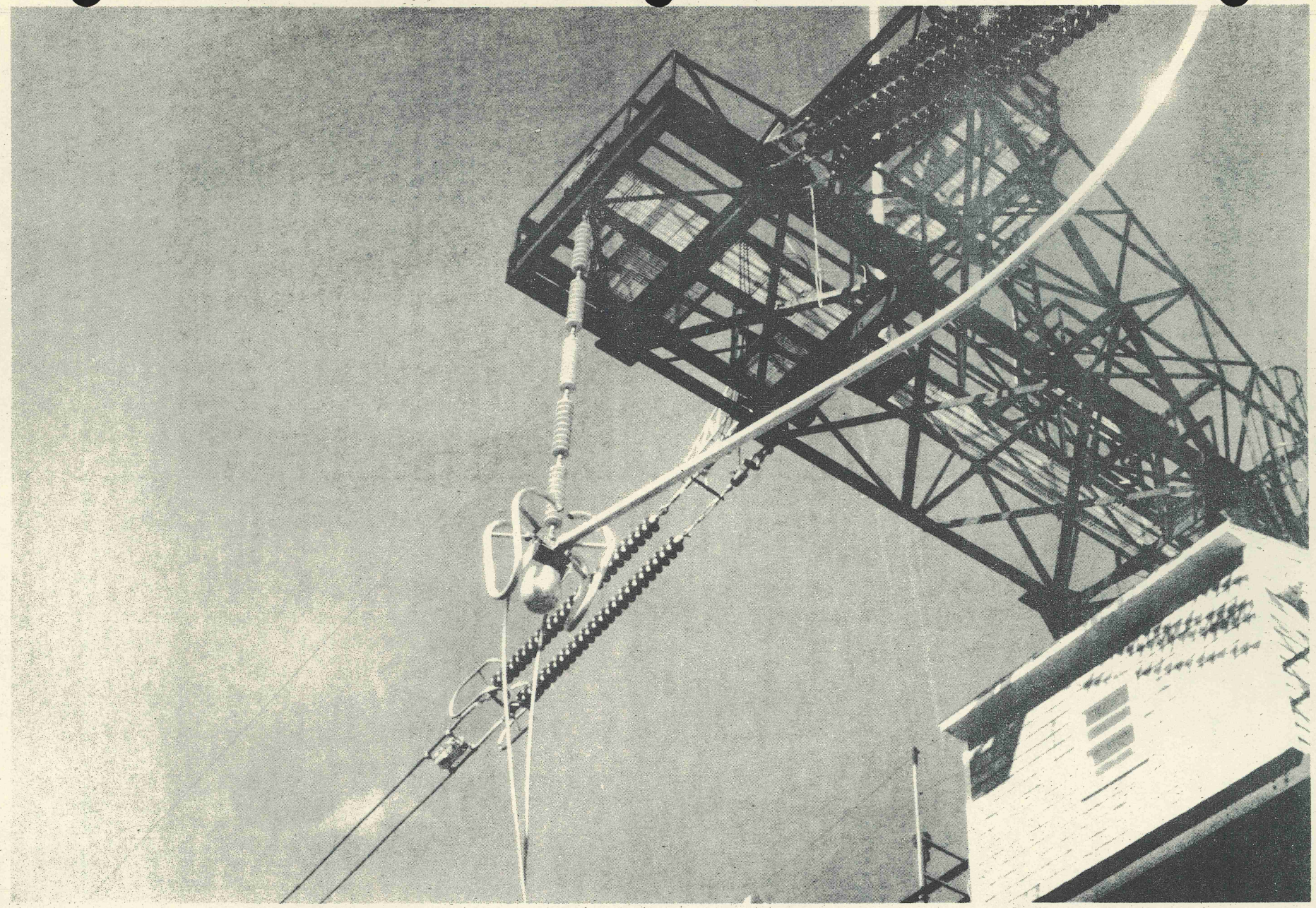


Fig. 12. Polymer Insulators on the General Electric Company EHV Line in Pittsfield, Mass.

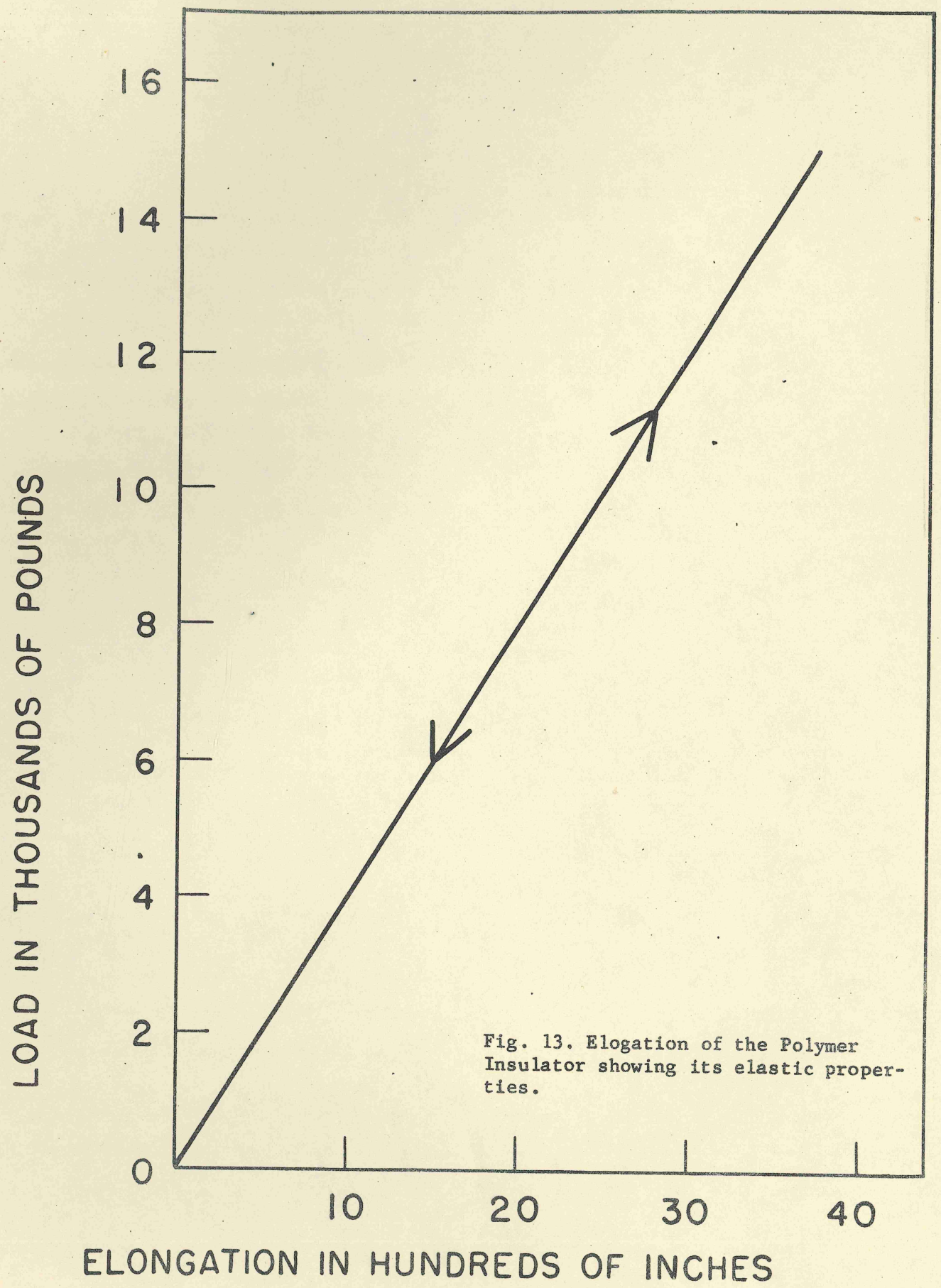


Fig. 13. Elogation of the Polymer Insulator showing its elastic properties.

Characteristics	Polymer Insulator	Rating Of Standard 7 Unit String Suspension Insulators 5-3/4 x 10"
Sixty Cycle Flashover, Dry, Kv	462	435
Sixty Cycle Flashover, Wet, Kv	352	295
Impulse Flashover, Positive, Kv	730	695
Impulse Flashover, Negative, Kv	683	670
R.I.V. (Microvolts at 80 Kv)	150	500
Arcing Distance, Inches	43	41-1/2
Leakage Distance, Inches	85-1/4	80-1/2
M.& E. Strength, Pounds	22,000	15,000
Weight, Pounds	22	77

Fig. 14. Comparison of the characteristics of a redesigned Polymer Insulator with a string of 7 porcelain insulators 10" in diameter, 5-3/4" spaced.

NEW THOUGHTS ON HIGH VOLTAGE INSULATORS

H. A. Frey, Mgr.-Engineering

Insulator Department General Electric Company

I very much appreciate this opportunity to present to the Electrical Equipment Committee some of the new thoughts on materials for high voltage insulators, and the problems associated with such material.

I know that your Committee's primary interest lies in electrical equipment and apparatus insulation rather than line insulation. However, in these two areas the fundamental insulating material problems are interchangeable so that I hope you will understand if many of my remarks are directed toward line insulators, since it is in this area that we have much of our total experience with some of the new materials for high voltage outdoor insulation.

Virtually all high voltage insulators, whether used in apparatus or as line insulation, must perform three basic functions:

1. They must provide mechanical support and so they must have mechanical strength consistent with their expected service load.
2. They must have adequate dielectric strength to support line voltage plus expected overvoltages due to surges.
3. They must be so designed as to make efficient electrical use of the surrounding medium, which in the case of outdoor insulators is air.

In the most general sense, the basic requirements for the materials of which high voltage outdoor insulators are made are shown in the following tabulation.

REQUIREMENTS FOR HIGH VOLTAGE INSULATING MATERIAL

a. Dielectric strength

b. Mechanical strength

c. Thermal shock resistance

d. Inert - Free from reaction with atmospheric contaminants or solar radiation over long exposures

e. Surface easily cleaned

f. High resistance to tracking

g. Ability to fabricate in many complex shapes

h. Economic

It would be meaningless to attempt to assign to each of the characteristics in the list of material requirements a specific number, since physical designs of insulators can usually be adjusted to take care of a wide range of specific characteristics. However, it must be borne in mind that a balance must be obtained in these values. For example, it would be perfectly possible to make an insulator of particular strength with materials having relatively low unit strength, but larger cross sections would be involved. This, then, must be balanced against the overall economics of the situation as well as the physical limits on size imposed by the application. However, irrespective of the balance which is reached between these fundamental material characteristics, we must bear in mind that the ultimate product must be capable of many years continuous and, in many cases, unmonitored operation.

For almost 75 years, the material that we know as high voltage porcelain has been very successfully used for nearly all outdoor high voltage insulator applications. This material has proved its effectiveness. Furthermore, improvements in the material which have been made continuously over the years have

raised its performance characteristics and its reliability to levels where it is indeed hard to beat. The high voltage electrical porcelain which is made today, while it goes by the same name, is in fact quite different from that with which the industry started nearly 75 years ago.

You may then wonder why we bother to try to generate new thoughts and new developments in high voltage insulating materials. To understand this, let us look very frankly at some of the weaknesses of porcelain.

WEAKNESSES OF PORCELAIN

a. Non-ductile

   1. Impact breakage
   2. Difficult to control stresses and avoid stress concentrations
   3. Though the ultimate stress in test bars may be as high as 15,000 - 25,000 p.s.i., it may be possible in some complicated shapes to realize only 2,000 to 4,000 p.s.i.

b. Designs are controlled by manufacturing limitations of the material.

   1. Material is made in final design form.

c. Long manufacturing cycle times.

   1. Influences delivery and service.

If a material eliminating some or all of these weaknesses could be developed without sacrificing the other characteristics, including economics, significant improvements might be made in the insulators of the future for both apparatus and line applications. It is possible that even if the new insulators cost more than the old, ancillary savings may be made which would make the new insulating system actually more economic than the present. To this end, the Insulator

Department of the General Electric Company initiated an investigation and development program in 1955 to study materials which may be suitable for high voltage outdoor insulator applications. As was expected, it was found that this was quite an undertaking. Bear in mind that insulators must be produced and used in huge quantities, with an extremely high degree of reliability and with normal life expectancy of 35 years or more. Some of the materials investigated were subject to degradation from the solar radiation, some did not stand normal atmospheric reagents, some had such poor dielectric or mechanical strength that they could not be economically used, and some tracked so severely as to be useless. After a substantial amount of work had been done, it became apparent that the two materials holding the greatest hope for the application were the butyl rubbers and the epoxies. Each of these, however, is a class of polymer with many composition types within the class. Furthermore, with both of these two materials, it was necessary to use some reinforcing means in order to obtain adequate mechanical strength in reasonable cross sections. It was quite obvious that these materials could not be considered practically adequate without simultaneously considering the physical designs which might be most adaptable to them. In other words, it was futile in most cases to attempt to simply substitute new material for porcelain in existing designs.

It was not until early in 1959 that these material problems and designs were crystallized to the point where it was possible to produce an actual line insulator made of polymer material. The epoxy compositions used in this patented insulator included antitracking compositions and was given the trade name GEPOL®. In 1959, after extensive laboratory tests and with the cooperation of the utilities involved, the first experimental insulators of this type were put on actual transmission lines for field trials. The first of these test installations was made at the Baltimore Gas and Electric Company. It was followed shortly thereafter by installations at the Florida Power and Light Company, and the New England Power and Light Company.

On the Baltimore Gas and Electric Company application, Photo 1, the line voltage was 110 Kv and the insulators had been designed for 69 Kv service, so that three porcelain insulators were placed in series with the polymer units on a tangent structure. On an adjacent strain structure, two 69 Kv polymer units were used in series (Photo 2). Florida Power and Light and New England Power and Light applications were made at 69 Kv with one polymer unit per string. These three test sites were selected to provide a range of temperature exposures from a hot climate with intense solar radiation in Florida, to relatively cold climates in the Boston area. The Florida application (Photo 3) was at Juno Beach, at a point where the transmission line was within a few hundred feet of the surf and where severe trouble had been experienced with porcelain insulators due to salt contamination. Later similar insulators were also placed in service in five unit strings on the EHV Pittsfield Project of the General Electric Company where they were exposed to voltages as high as 750,000 volts (Photo 4).

In 1963, some of the insulators from the field tests were returned to Baltimore for very complete laboratory examinations, and tests were made to determine whether any degradation of the material had occurred. These tests were made in Baltimore, in Pittsfield, and at the General Research Laboratory in Schenectady. They gave no indication of deterioration.

It was decided in 1963 to initiate a much larger field test with insulators made for 115 Kv instead of 69 Kv service. Photo 5 shows a comparison between the units made in 1963 and a string of electrically and mechanically equivalent porcelain insulators. It is significant to note that the polymer units weighed 22 lbs., while the porcelain insulators weighed about 75 lbs.

During 1963 and 1964 approximately 1,700 insulators of this type were placed in test service by 68 utilities. Photo 6 shows one of these test applications on the Duke Power 100 Kv system. By deliberate plan, most of these insulators were

put in locations where operating conditions were expected to be abnormally severe, particularly in relation to atmospheric contamination. Today, after a weighted average exposure time of approximately one year, about 1-1/2 percent of the insulators placed on test have failed by surface tracking. It is significant to note that all of these tracking failures have occurred in areas involving very severe atmospheric contamination. It is also significant to note that there have been no mechanical failures nor any end to end electrical failures through the dielectric medium itself. The failures have all been due to surface tracking. Photo 7 shows one of the field test units which failed by tracking.

Laboratory work has been underway for the past nine months to find a means of correcting the tracking problem and it seems quite likely that an answer is in sight. However, we must remember that no laboratory test canreliably duplicate all field conditions and ultimately additional field tests will be necessary before this question can be considered solved. It is interesting to note that even severe and sustained flashover tests like this (Photo 8) do no harm.

During the same period, other insulators have been made experimentally for both field and laboratory trials. Photo 9 shows an experimental pin type insulator which was placed in experimental service in Brownsville, Texas, in an extremely contaminated area in 1964.

To give you some idea of the possibilities inherent in polymer insulators of the type which we are discussing, Photo 10 shows a radio antenna insulator which has been experimentally made of polymeric material and is still under investigation. It has an ultimate strength of nearly 1 million lbs. and is being studied for possible use in guying high voltage, low frequency Loran antennas. The insulator in the photo weighs approximately 600 lbs. and is electrically and mechanically equivalent to two porcelain insulators in series with a total weight of 3,000 lbs. One can imagine the gains in tower construction which could be made through use of polymer insulators of this type, since in most cases it would be necessary to use more than 200 porcelains per tower.

In 1964, in cooperation with the Power Switchgear Department of the General Electric Company, the Insulator Department undertook to make the insulators for the current transformer stacks of three 500,000 volts air blast breakers. These insulators were made in one piece. Each insulator was 15 ft. long with an inside diameter of 3 ft. and an outside diameter of about 44 inches. Insulators of this size and type had never before been made in one internal piece of porcelain, or any other material. Dr. Klint has already given you many of the details of these insulators. You may be interested, however, in a few photographs showing the construction of these units.

In order to withstand the internal pressures as well as the longitudinal compressive loads, it was necessary to use an epoxy bonded fiber glass core since the epoxy itself would have inadequate strength and mechanical creep characteristics. Photo 11 shows the epoxy bonded fiber glass core in the process of internal pressure tests in our Baltimore laboratory. Each of these cylinders was required to stand internal pressure of 330 lbs. per square inch. The cage-like longitudinal bars that you see in the photograph are the restraining rods to hold the headers in place during the test. The total pressureon the headers was 335,000 lbs. during this test. The polymer bonded fiber glass tube alone weighed approximately 1,000 lbs.

Photo 12 shows the epoxy encapsulation being cast. The fiber glass tube has been centered in this steel mold and encapsulating material is being cast into the annular space between the tube and the mold. Approximately 5,000 lbs. of material was cast to make each of these huge elements.

Photo 13 shows the castings being cured in the moulds using automatically controlled electrical heating elements.

Photo 14 shows the castings being prepared for electrical test in the high voltage laboratory in Baltimore. Each unit was tested to over 2,000,000 volts impulse.

Photo 15 shows the casting in the final process of machining.

Three of the huge insulators are here shown (Photo 16) mounted in place on a 500 Kv air blast breaker in Philadelphia.

Now let us look at some other applications of polymeric material to the exposed insulating members of apparatus.

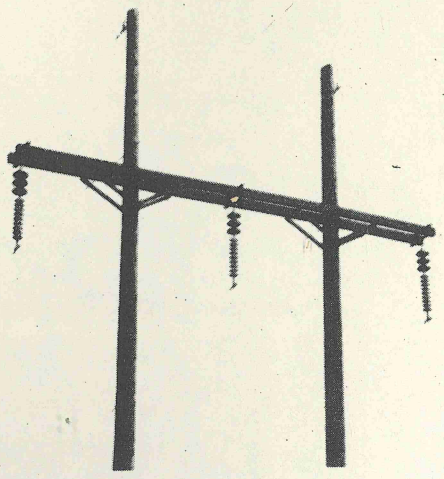
Probably the earliest commercial and practical application of polymeric insulation to outdoor insulators was that developed by the Meter Department of the General Electric Company. This made use of a special butyl rubber compound, employing antitracking ingredients for the encapsulation of patented current transformers. Such equipment is now made for voltage as high as 69 Kv. Photo 17 shows typical dry type current transformers with butyl rubber insulation. Photo 18 shows typical potential transformers so insulated. Equipment of this type has been in successful outdoor use for years.

More recently the Distribution Protective Equipment Department of General Electric has developed a patented fuse cutout employing butyl insulation. This device is shown in Photo 19. The device has been in the field for three years and more than 100,000 are now in service. Field experience has been excellent. The device is lighter and has much higher mechanical shock resistance than former cutouts. Photo 20 shows the new cutout in service in a practical application.

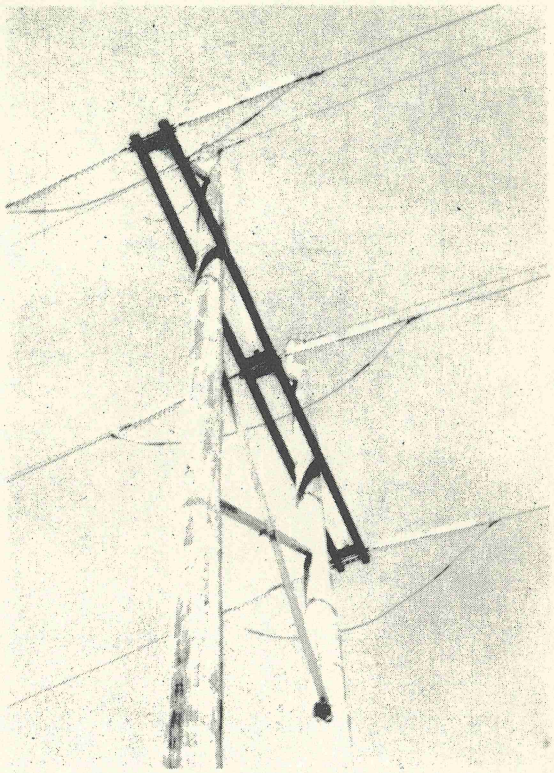
The new "SEAL PAC"^{TM} transformer developed by our Distribution Transformer Department provides another example of the use of new insulating materials for outdoor application. The "SEAL PAC" transformer is shown in Photo 21 in comparison with a conventional transformer. The high and low voltage bushings are made of a special epoxy composition employing antitracking ingredients. Photo 22 shows the patented high voltage bushing in some detail. Field reports are excellent, with no indication of tracking or other degradation of the material.

From these remarks you will see that much work has already been done in action as well as in thought toward the development of new high voltage insulators employing polymeric materials. I believe we may conclude that when carefully selected and formulated, such materials already have been proved successful in those applications where relatively high electrical safety factors can be used and where the voltage is not too high relative to insulator size and leakage distance. This is demonstrated by the last three examples cited--the current transformer, the fused cutout, and the "SEAL PAC" transformer.

Where the economic balance or physical clearances prohibit liberal designs, the case is not yet clear. The high voltage line insulator experiments have shown that while GEPOL insulators perform well in most cases, there has been surface tracking in about 1-1/2 percent of the applications. In the form employed in those trials, the insulators would not be suitable for general high voltage line use. However, it appears that they are quite close to success. In fact, they may be no worse now than were porcelain insulators at the equivalent stage of their development. On this score, we must await the results of work now in progress before drawing conclusions.



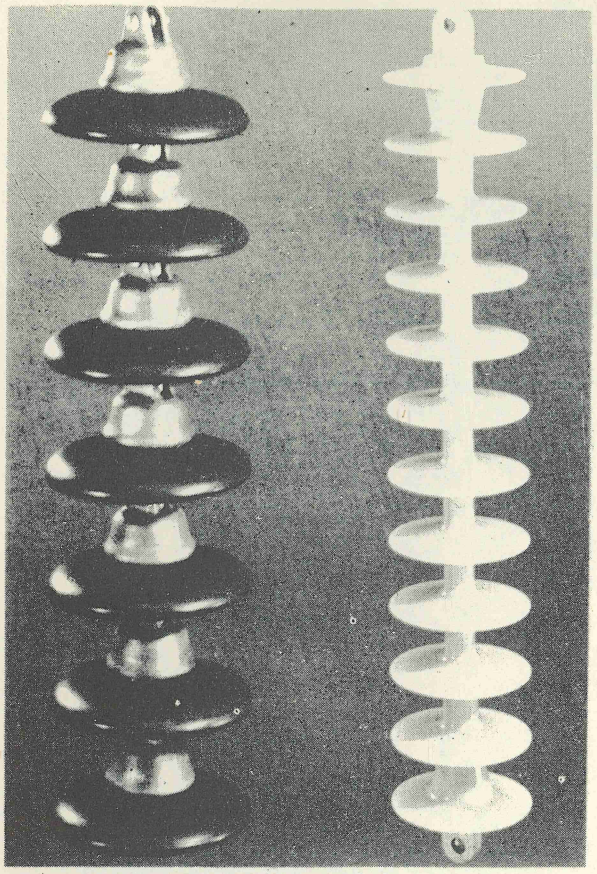
1. Polymer Insulators -
Baltimore Gas & Elec. Co.
110 Kv



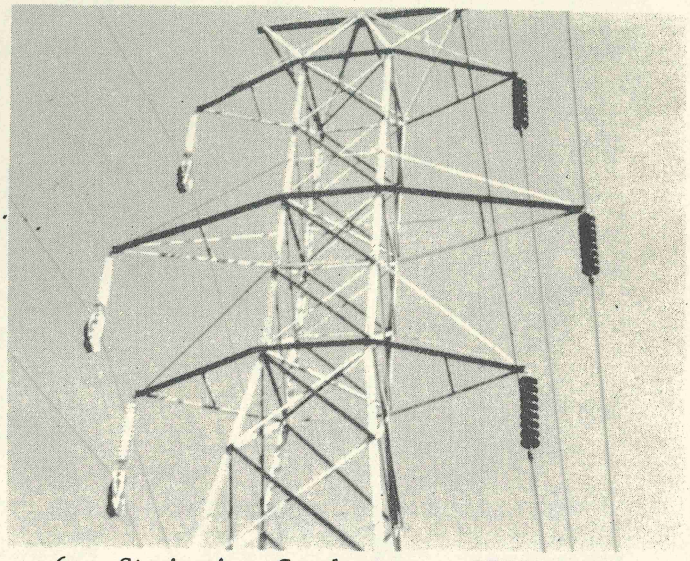
2. Polymer Insulators -
Baltimore Gas & Elec. Co.
110 Kv

3. Polymer Insulators -
Florida Power & Light Co.
69 Kv

4. Polymer Insulators -
Pittsfield EHV Project

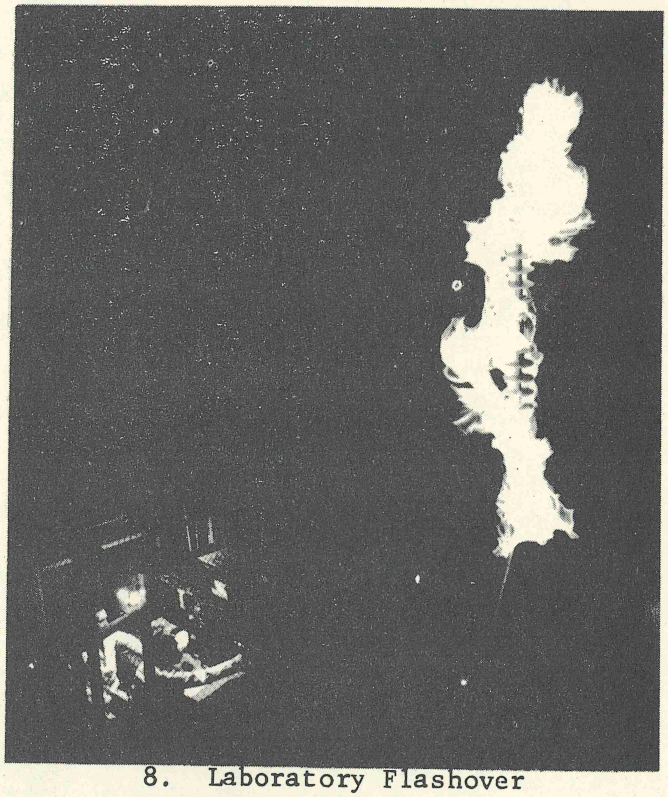


5. 115 Kv GEPOL Insulator and Equivalent Porcelain Insulators

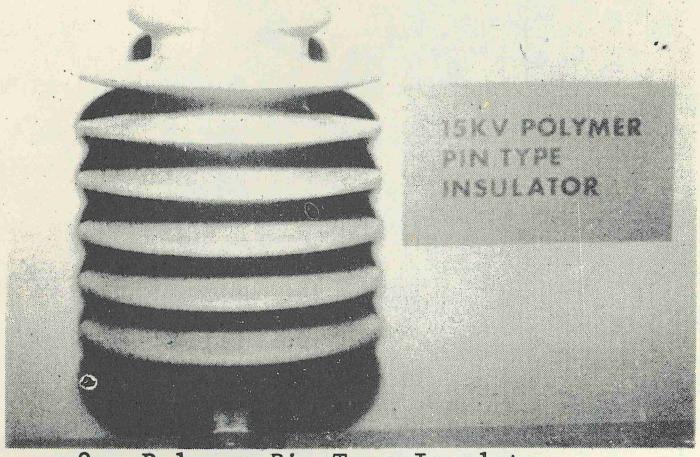


6. Stringing Conductor - GEPOL Insulators - Duke Power Co. 100 Kv

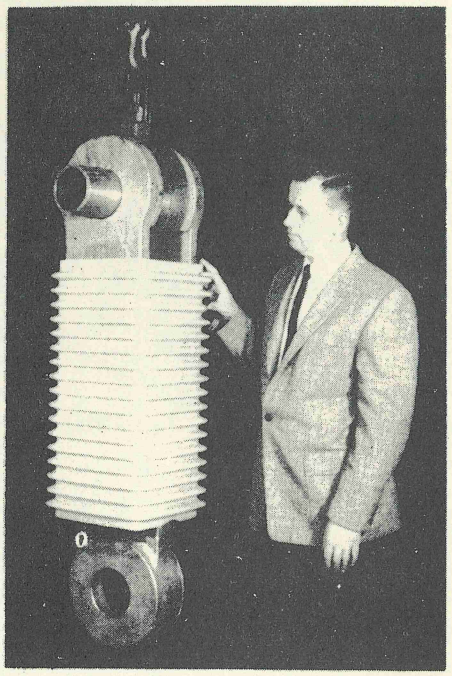
7. GEPOL Insulator Tracked on Field Trial



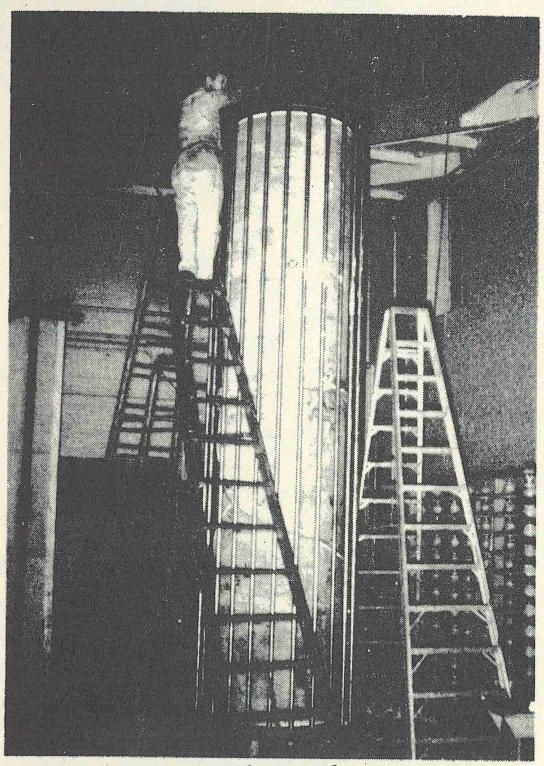
8. Laboratory Flashover Test - GEPOL Insulator



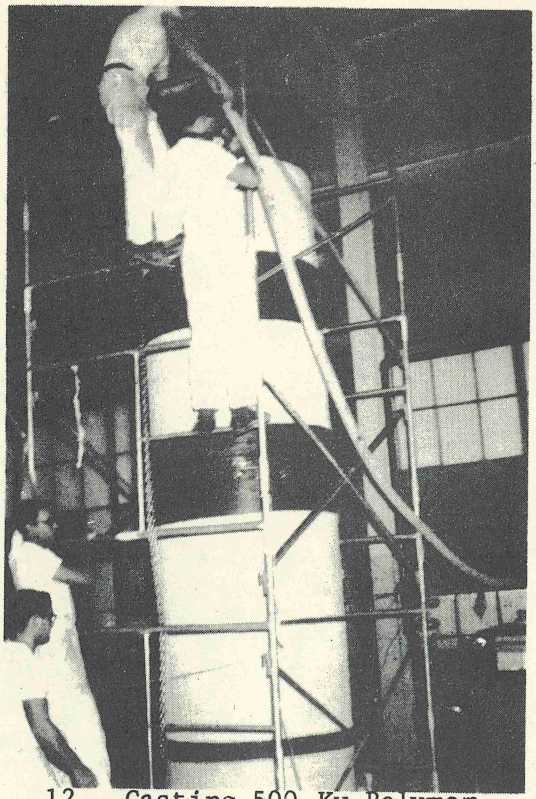
9. Polymer Pin Type Insulator
City of Brownsville, Texas



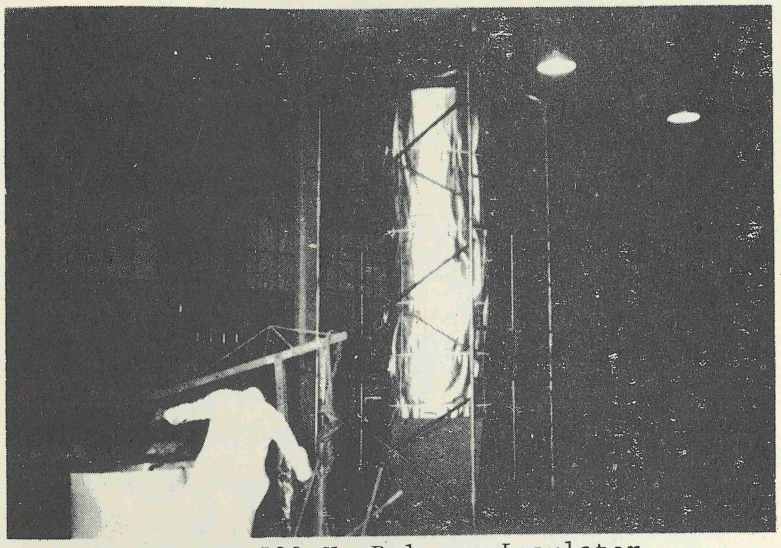
10. Polymer Antenna
Insulator - 1 Million
Lb. Strength



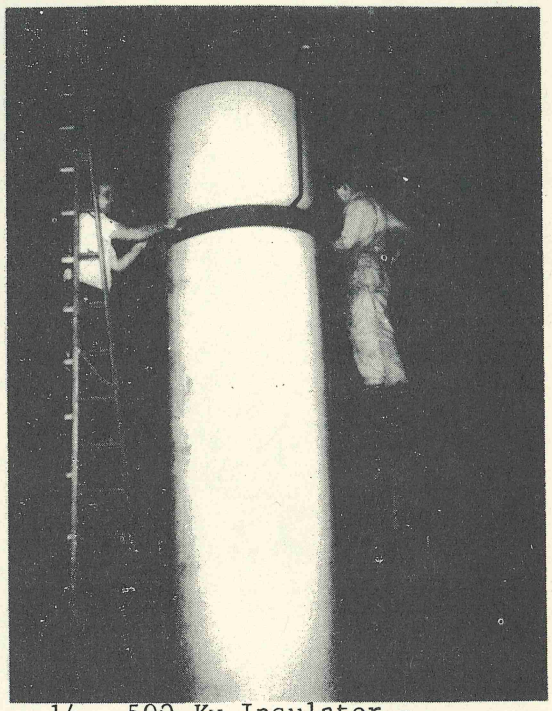
11. Epoxy Fiber Glass Core
for 500 Kv Insulator -
Pressure Test



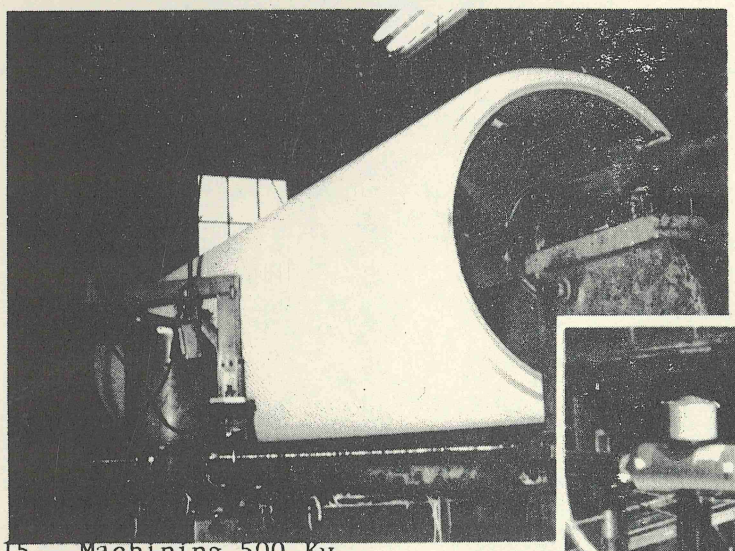
12. Casting 500 Kv Polymer
Insulator



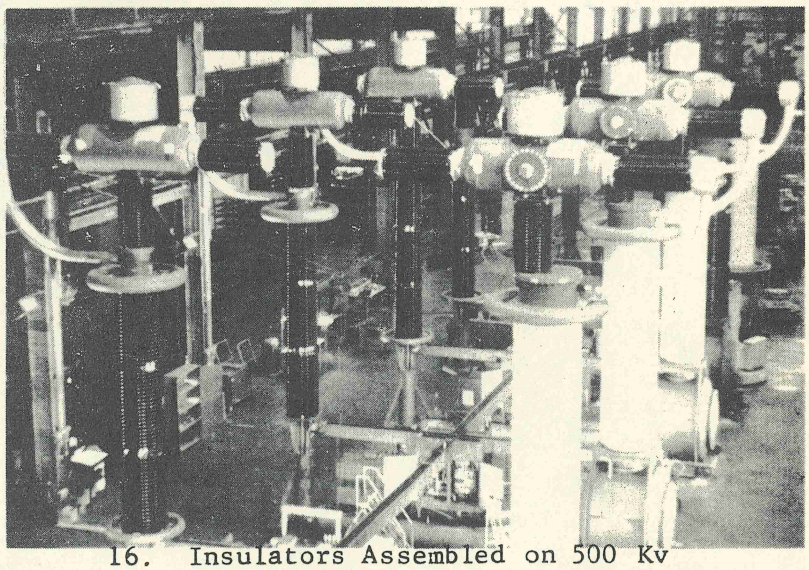
13. Curing 500 Kv Polymer Insulator



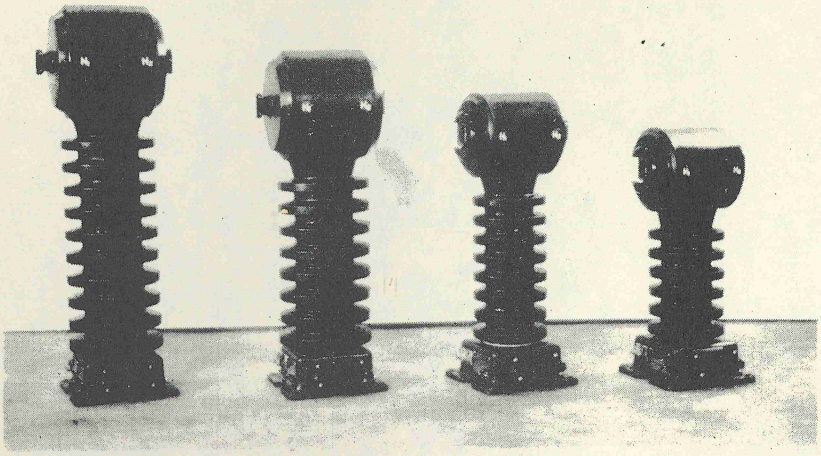
14. 500 Kv Insulator - Preparation for Electrical Tests



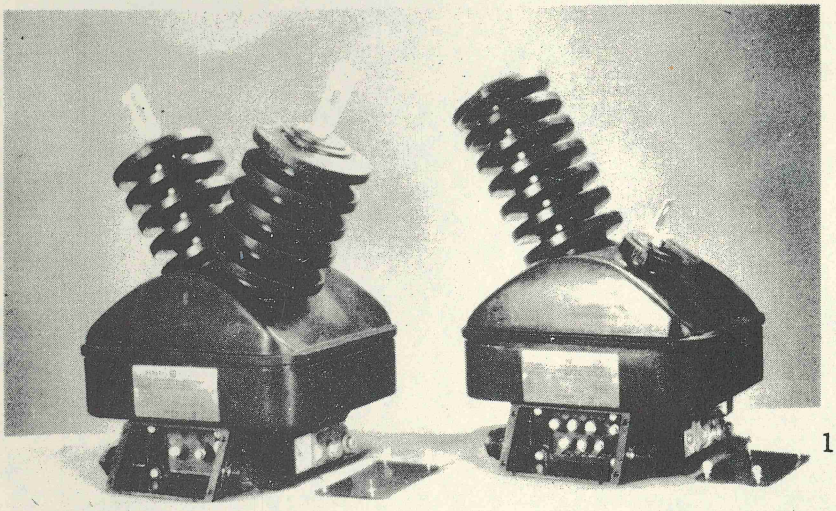
15. Machining 500 Kv Polymer Insulator



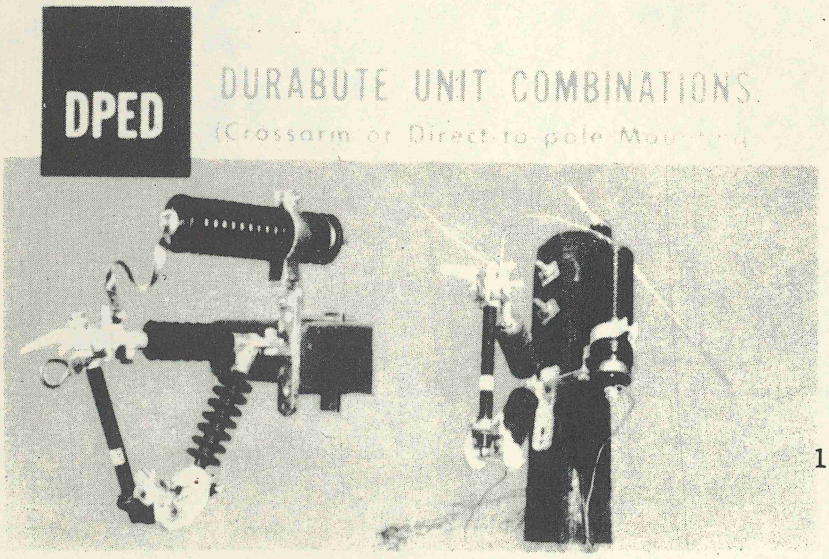
16. Insulators Assembled on 500 Kv Air Blast Breaker - Philadelphia



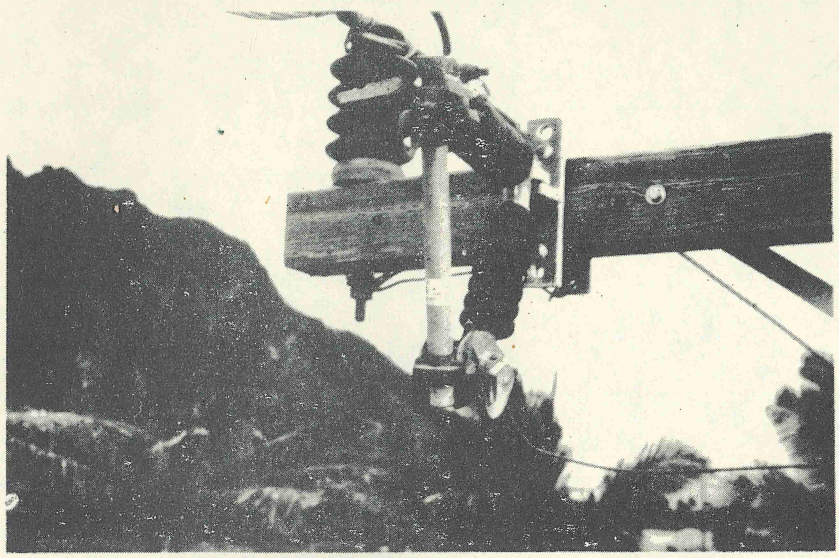
17. Current Transformer with Butyl Insulation



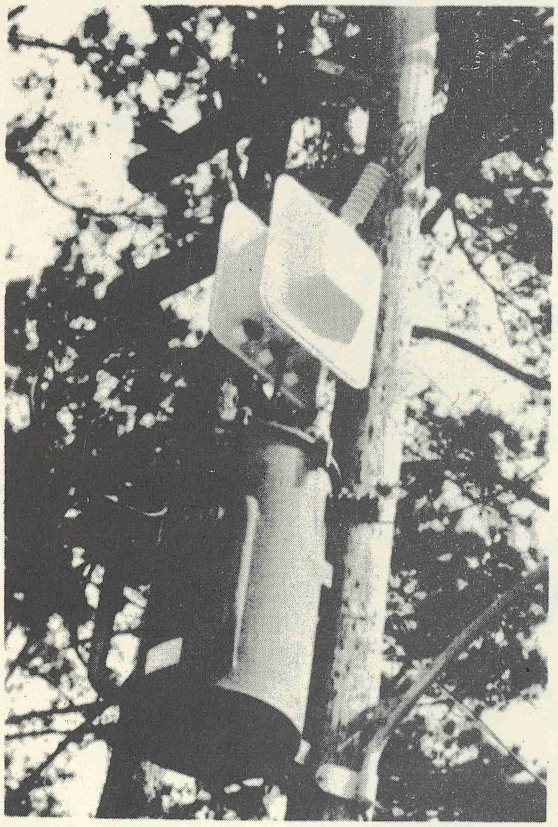
18. Potential Transformer with Butyl Insulation



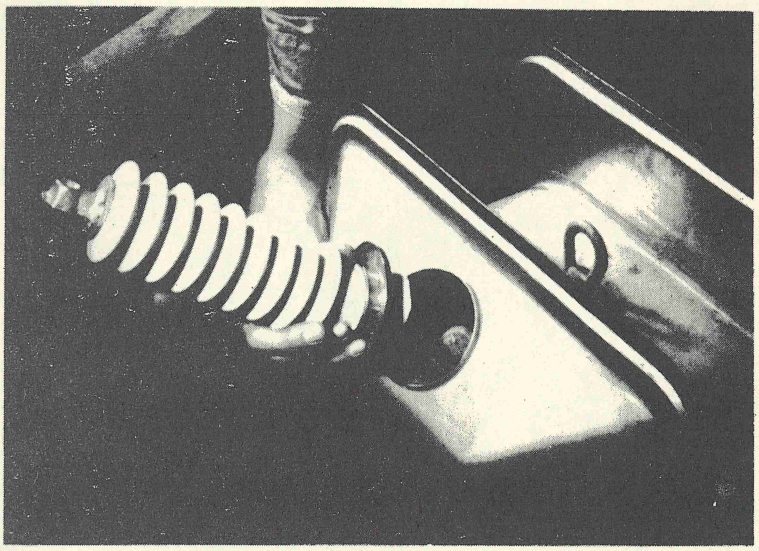
19. Fuse Cutout with Durabute Insulation



20. Cutout with Butyl Insulation in Service



21. "SEAL PAC" Transformer with Polymer Bushing Compared with Conventional Unit



22. Polymer Bushing on "SEAL PAC" Transformer

Conference Paper

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F. C. Vose
Senior Member IEEE
General Electric Company
Baltimore, Md.

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Paper No. CP
64-36

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Fred C. Vose

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INSULATOR TESTS

Electrical Flashover Tests.

Sixty cycle wet and dry flashover tests and impulse positive and negative flashover tests were made on these insulators in accordance with ASA Standard C-29.1 entitled "American Standard Test Methods of Electrical Power Insulators." The results of these tests are shown in Figure 4 for 1, 2, and 3 units. A comparison with the rating established is also included.

Radio Influence Voltage (RIV) and Corona Tests.

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Barometric Pressure 29.81 Inches
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It is concluded from these tests that the switching surge flashover characteristics of the polymer insulators are equivalent to those of porcelain insulators.

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Volt time tests were made on a single insulator and on two insulators in series, both positive and negative polarity. The results of these tests are shown in Figures 8 and 9.

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In all cases the breaks on the polymer insulators were quite different from the breaks normally experienced with porcelain insulators. On the polymer insulators the breaks occurred at the point of impact with the hammer of the test machine, but only a very small section of the skirt broke away from the insulator, and after the test each insulator was both mechanically and electrically sound.

In an effort to determine how rugged the polymer insulator might be several units were dropped from the top of an 18 foot ladder on to a concrete floor. Units dropped in a horizontal position sustained no damage and were mechanically and electrically sound

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CONCLUSIONS

An analysis of the data presented indicates that the new polymer suspension insulator has electrical characteristics equal to or better than the equivalent strings of the conventional 5-3/4" spaced 10" diameter porcelain suspension insulator. The data also indicates that this insulator readily meets the ratings which have been established for a single unit and for two and three units in series.

Mechanically it appears that from laboratory tests the insulator is adequate for service on high voltage transmission lines and should perform equally well or better than its porcelain insulator equivalent. The important characteristic, life expentancy, remains unknown. The determination of this characteristic will require extensive field testing as well as continued laboratory tests.

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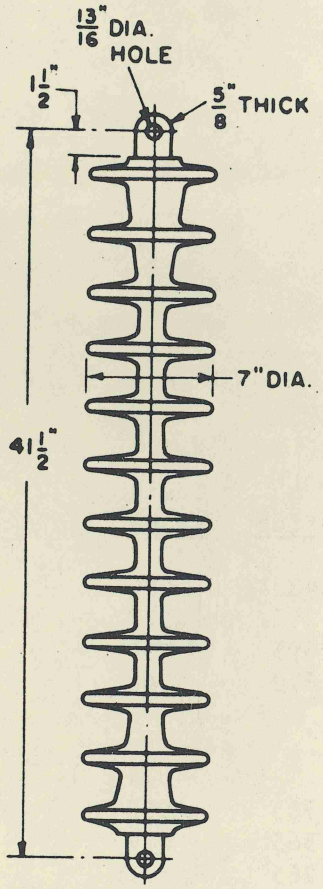

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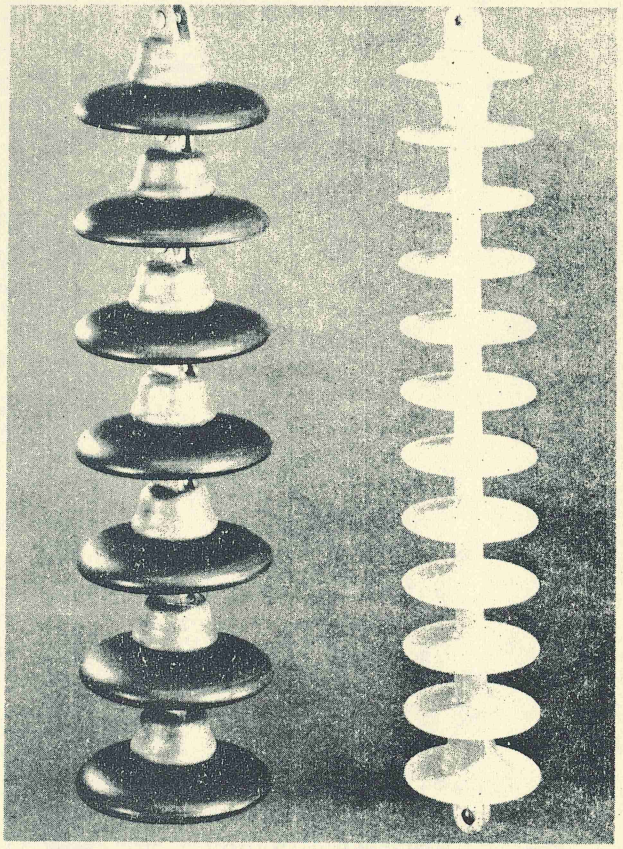

Fig. 2. Polymer insulator compared with a string of (7) seven suspension insulators.

Characteristics	1 Unit	2 Units	3 Units
Sixty Cycle Flashover, Dry, kv	435	785	1 100
Sixty Cycle Flashover, Wet, kv	295	565	780
Impulse Flashover, Positive, kv	695	1 265	1 825
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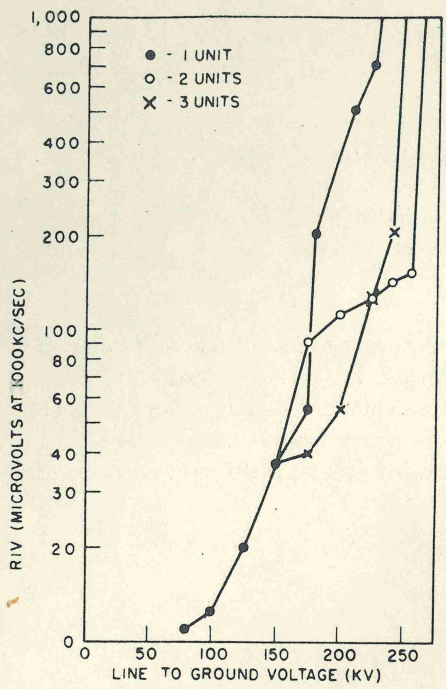
Sixty Cycle Wet Flashover Voltage, kv	780	917
Impulse Flashover Voltage, Positive, kv	1 825	2 210
Impulse Flashover Voltage, Negative, kv	1 870	2 230

Fig. 4. Electrical test values of polymer insulators compared with ratings.



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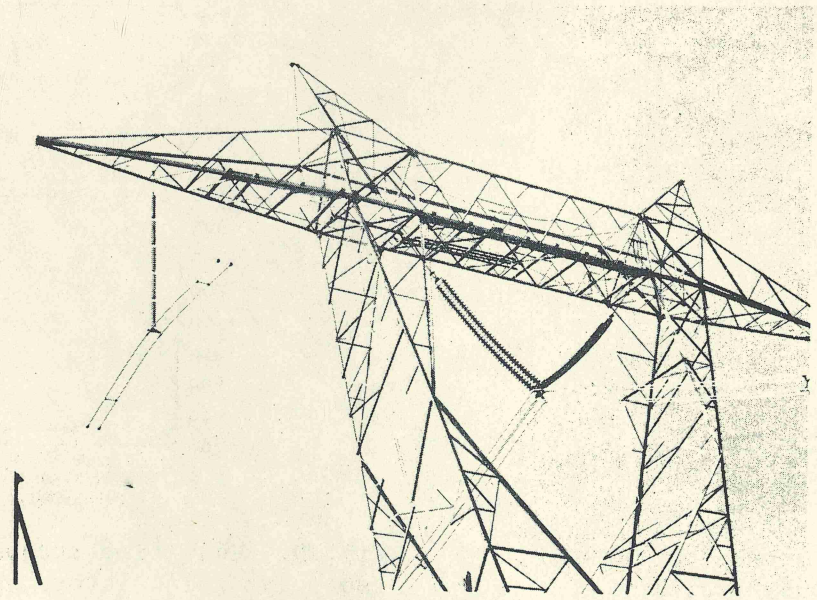

Fig. 6. 700 kv tower with five polymer insulators mounted for switching surge tests.

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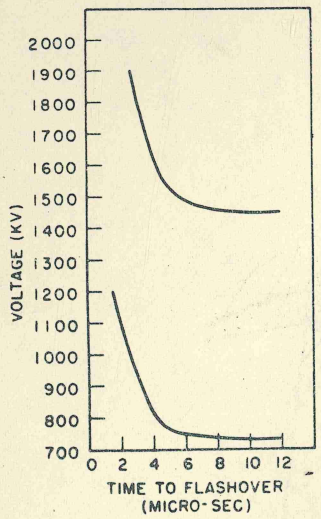
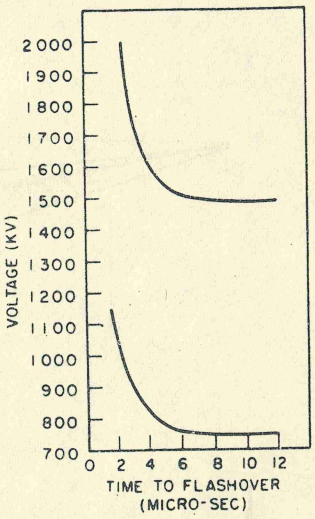


Fig. 8. Volt time curves for one and two polymer insulators, positive polarity.



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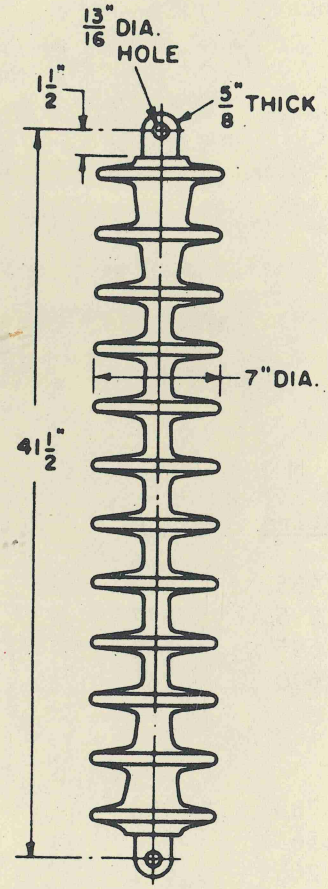

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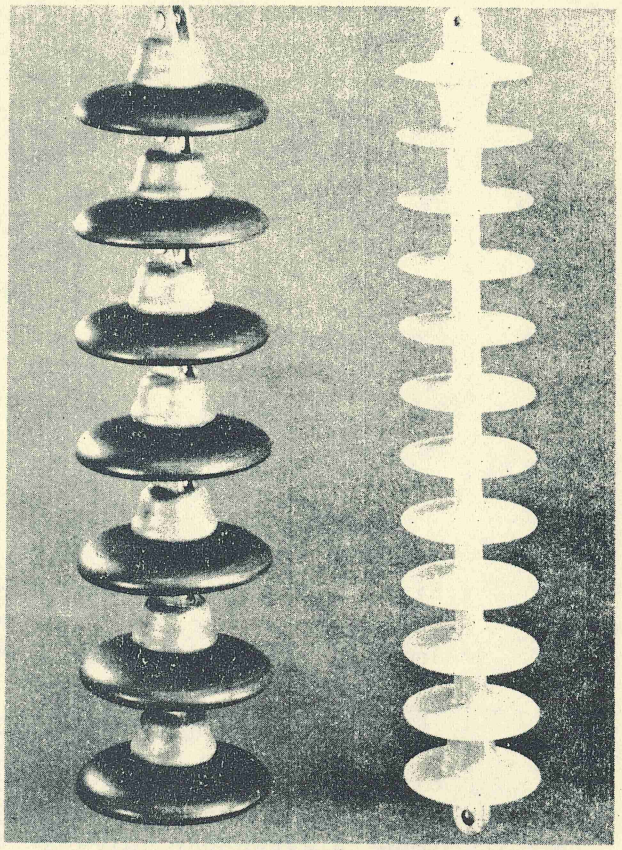

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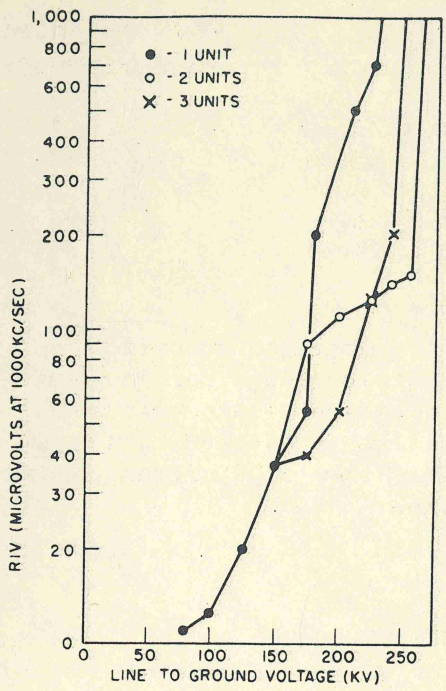

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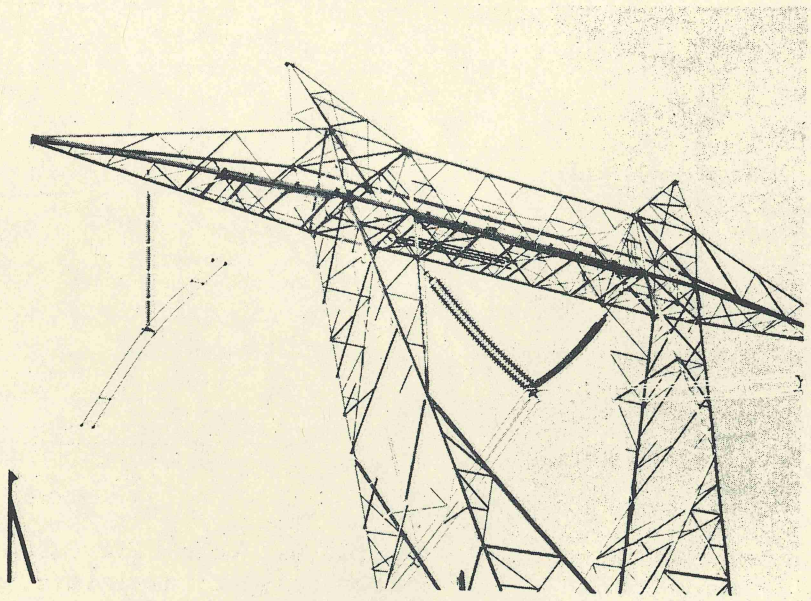

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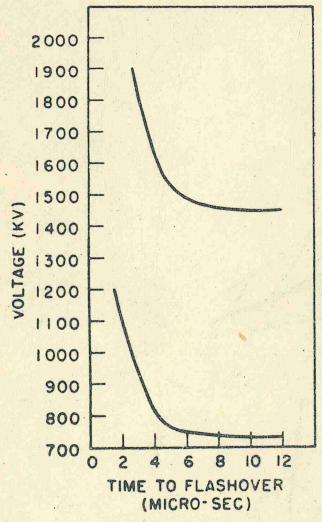

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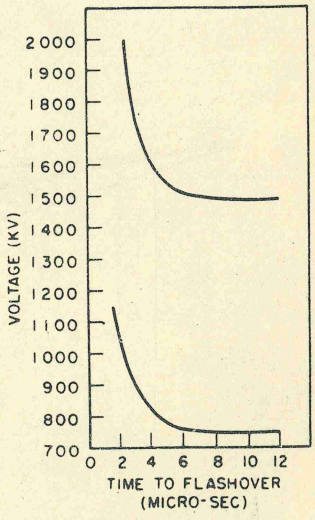

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FIELD SERVICE TRIALS OF POLYMER INSULATORS FOR HIGH VOLTAGE TRANSMISSION LINES

F. C. Vose

SUMMARY

The first report on GEPOL® insulators for high voltage transmission lines was presented at the 1963 Summer Annual IEEE meeting in Toronto (CP-63-1039) and a second report on these insulators was presented at the IEEE Winter Power meeting in New York in 1964 (CP-64-36). These two papers reported on the original concept of a polymer insulator and the limited field trials of the insulator, as well as on the laboratory tests and characteristics of a revised design of the original polymer insulator. Since the publication of these two papers, the revised design has undergone extensive field service tests on the transmission lines of many utilities in the United States, under widely varied atmospheric conditions. This paper has been written as an interim report on the results of these field service tests and to present a detailed description of the insulators and the laboratory tests that have been made on insulators returned from field service, with varying periods of time in the field.

INTRODUCTION

In order to keep track of all parameters in this large scale field trial, the following steps were taken:

1. Each insulator manufactured was marked with a serial number. The date of its manufacture and conditions relating to the manufacturing process were recorded.

2. Each utility participating in the field trials was asked to return a questionnaire on the details of the installation of the insulators. This provided information on the date of installation, the voltage applied and any pertinent details concerning exposure, such as degree of contamination and kind of contaminants involved in the exposure.

3. Records were kept of the serial numbers of the insulators and the exposure as indicated by the returned questionnaires.

It was suggested to the sixty-eight utilities cooperating in the field trials that at least some of the exposure be made in severe locations so that a true cross-section of operating conditions would be obtained. Actually, of the approximately 1,700 insulators in service, a disproportionately high percentage was placed in areas involving severe contamination of various kinds.

The first insulators of this design were placed in service on field trial in October, 1963, and additional quantities have been put into service at intervals since then. Some of the 1,700 insulators presently in service have been operating for seventeen months and some of the more recent units have been in service for only a few months. The weighted average service time is probably about six months.

Of those insulators which have been placed in areas subject to abnormally severe contaminants, the contaminating materials covered a wide range including salt, gypsum, coal dust, fertilizer dust, fly ash, limestone, phosphates, acid fumes, cement, potash dust and heavy industrial contamination. In these field trials none of the insulators of this design were washed, even though in some cases porcelain insulators, when used in these same exposures, were subjected to regular washing operations.

In several cases the insulators were placed in areas which have been notorious for vandalism and where porcelain insulators were regularly broken by rifle fire.

RECORD OF RESULTS TO DATE

As of March, 1965, insulator failures have been reported involving a total of twenty insulators on eight different utility systems. In all of these cases, reports from the field indicate that the insulators were operating under contamination conditions which were either abnormal for the area, or which were deliberately selected to be extremely severe.

In each of these twenty cases the failure took the form of surface tracking or burning, or was associated with a puncture through the sidewall of the insulator to the encapsulated hardware. When such punctures occurred, a part of the effective insulator length was short circuited but in no case did the insulator puncture electrically end to end. In all cases the insulator still had effective insulating value even after the failure occurred. Had the insulators in this condition been allowed to remain in service, however, it is possible that ultimately they would have been totally destroyed.

Table I lists all of the failure areas and shows the system voltage, the date the insulators were installed and removed, and the condition upon return to the laboratory. The column headed "Number Punctured" indicates those units returned which had sidewall punctures to the encapsulated hardware. Also, the number of damaged insulators in the column headed "Number Burned" is not additive since in most cases punctured insulators were also burned. The total number of damaged insulators was twenty.

Photograph Fig. 1 shows a typical burned insulator and is one of the units returned to the laboratory from Jersey Central Power and Light Company. Photograph Fig. 2 shows a typical unit with side wall puncture, but without any other surface burning. This unit was returned from the Indiana & Michigan Electric Company.

DETAILS OF THE EXPOSURE AT THE TEST LOCATIONS

1. Memphis Light, Gas and Water Division

The Memphis Light, Gas and Water Division installed six GEPOL insulators nominally rated for 115 Kv service on their 115 Kv system in March, 1964. These units were installed in an area where severe contamination of calcium carbide from a nearby chemical plant could be expected. They have had serious trouble with flashovers of conventional cap and pin type insulators in this location. The GEPOL insulators were not washed. In October, 1964, one insulator was reported to have flashed over. All six insulators were removed from service and were returned to the laboratory for examination and tests. Five of the six GEPOL insulators were found to be in perfect condition. The sixth insulator, Serial #500, was found to be punctured through the sidewall at the root of the hood of the first corrugation. Despite this, its wet flashover voltage was still 312 Kv, which is only about 15 percent below that of undamaged insulators after the same exposure.

2. Niagara Mohawk Power Corporation

In May, 1964, Niagara Mohawk Power Corporation installed six of the nominally rated 115 Kv polymer insulators on their 115 Kv system near Niagara Falls, New York. This was known to be a very severely contaminated area. The operators report that because of the severe contamination normally about ten fog type porcelain insulators are used, yielding a leakage distance of 170 inches. For this test, however, a single GEPOL insulator was installed in each location providing only 85 inches of leakage distance. When porcelain insulators are used, it is the normal practice either to coat them with silicone grease or to wash them regularly. For this reason, three of the GEPOL insulators were grease coated and three were left uncoated but were <u>not</u> washed. In November, 1964, a flashover occurred on one of the uncoated GEPOL insulators. An examination of the entire group showed that all had varying degrees of tracking or

burning. These insulators were removed and cleaned before returning them to the laboratory for tests. It was found that while one of the uncoated units had flashed over, the units which had been coated with silicone grease showed more severe surface burning and the pattern of the surface tracking was different from that on the uncoated insulators. Those insulators which had been coated with greased showed a great number of relatively fine track marks scattered around the surface and in some cases were not continuous. Fig. 3 shows one of the units which had been grease coated. It would appear as though the grease had become overloaded with contaminants, resulting in the passage of leakage currents at the interface between the grease and the polymer. In this case the grease would, of course, confine the heat generated by the leakage currents, which could produce the type of tracking observed.. This experience would make questionable the desirability of using silicone grease on polymer insulators in contaminated locations. However, further exploration should be made of this subject before positive conclusions are reached.

It should be noted that on only one of the Niagara Mohawk insulators was puncture detected in the side wall and this was on the uncoated insulator which had flashed over. On this insulator the wet flashover was 253 Kv. The balance of the insulators had wet flashover values from 311 Kv to 393 Kv. Despite the rather severe apparent burning, all insulators were capable of supporting line voltage.

3. Appalachian Power Company

The Appalachian Power Company installed six of the 115 Kv rated insulators on their 138 Kv system in two areas in January, 1964. Each of these areas was subject to chemical contamination. In one insulator contamination was believed to be minimal. In the second insulator, contamination was expected consisting of limestone dust from a chemical plant and residue from the stack of a dry ice plant. It was reported that in December, 1964, one of the insulators in the first location was inspected and showed burn marks from flashover and it was coated with a light coat of dust. Several days later the insulator flashed over many times during wet and rainy weather. It was then removed and returned to the laboratory for inspection and tests. No damage was reported on the remaining insulators, and they were left in service.

Upon examination, the insulator showed very severe damage from the conditions of service and the flashovers. Ten of the twelve hoods were punctured at the core, the sidewall was punctured at the point of hardware encapsulation at both ends, and the entire unit was severely burned and charred. Fig. 4 is a picture of the damaged insulator. The wet flashover of the insulator was measured in the laboratory on the returned insulator at 123 Kv. Its insulating capability had been very seriously reduced as a result of the extreme burning and charring. The unit was tension tested to destruction. It failed at 18,200 lbs., about 11 percent below its rated ultimate strength when manufactured.

4. Jersey Central Power & Light Company

This utility installed a total of six 115 Kv GEPOL insulators in February, 1964, on a 230 Kv circuit using two GEPOL insulators per string. Normally this part of the Jersey Central system is considered to be a reasonably clean, rural location although there is usually a minor amount of salt contamination blown in from the coast. However, at this particular time there was a severe drought in the area with no rain reported from June until September 23, 1964. On September 23 during a long, misty rain all insulators on the line, porcelain and polymer alike, were reported to be showing localized sparking and the operators expected flashover to occur momentarily. No flashover occurred, however, on either the GEPOL or porcelain insulators. In the evening of September 23 a heavy washing rain cleared the trouble. Subsequently on routine inspection of the line the operators noticed that the surface of the GEPOL

insulators was tracked and the insulators were removed. On laboratory examination, it was found that five of the six insulators showed substantial degrees of surface burning and tracking, and four had punctures through the sidewall. All were capable of supporting line voltage, however, and had done so for a period of several weeks, from the period of the trouble to the date of removal. Fig. 1 is a picture of one of the returned insulators.

5. Virginia Electric and Power Company

In October, 1963, the Virginia Electric and Power Company installed six of the 115 Kv polymer insulators on their 110 Kv system. Three of these were installed in the rural area of the system and have given no trouble to date. Three were installed adjacent to a Portsmouth substation in an area known to be subjected to severe contamination from salt, coal dust, and fertilizer dust. In October, 1964, during a rainy period, several flashovers occurred on two of the polymer insulators over a period of about six hours. On subsequent examination all three insulators were found to be badly burned and had sidewall punctures. The worst unit had a wet flashover of 162 Kv. Nine of the twelve skirts were punctured at the core of this insulator.

6. Tampa Electric Company

In July, 1964, the Tampa Electric Company installed three 115 Kv GEPOL insulators on their 69 Kv circuit in an area subject to severe atmospheric contamination. Two of these insulators showed surface burning or tracking in January, 1965, and were returned to the laboratory for testing. These insulators were very heavily coated with contamination which was quite adherent and completely covered them. One of the two insulators exhibited sidewall punctures. Analysis of dirt scrapings from the surface confirms the fact that it was a mixture of quartz and a complex hydrated sodium calcium phosphate.

7. Houston Lighting and Power Company

The Houston Lighting and Power Company installed three 115 Kv polymer insulators on their 69 Kv system in a highly contaminated area in July, 1964. In January, 1965, burning was noted on one of these units and upon return it was found to be both severely burned and punctured in the sidewall. The insulator was heavily coated with a white film, which on analysis was found to be a mixture of magnesium oxide and hydrated magnesium oxide.

8. Indiana and Michigan Electric Company

The Indiana and Michigan Electric Company installed three 115 Kv polymer insulators on their 138 Kv system in December, 1963. The installation was made in a rural area where only farmland dust was anticipated as a contaminant. In January, 1965, an inspection was made of these units and some discoloration on the top skirts was observed and a light film of contamination was observed on the insulators. On one insulator the sidewall showed a small area between the first and second hoods which appeared to be punctured. Due to the observed condition of the insulator, it was decided to remove all three of them from service and return them to the laboratory.

Laboratory examination and test showed that two of the insulators returned were not damaged in any way but they were coated on the top end with a light film of contaminant. The third insulator was punctured through the sidewall at the point where the hardware is encapsulated. Fig. 2 is a picture of the returned unit.

Table II lists by serial number the details of the electrical condition of each of the insulators that have been returned by the participating utilities. This table shows in column one the serial number, in column two the name of the utility where the exposure was made, in column three a record of the sidewall location of the puncture. The number in column three indicates the location of the puncture counting from the root of the first corrugation at the energized end. The last column shows the wet flashover of the insulator in the condition in which it was received in the laboratory.

CAUSE OF SURFACE BURNING AND TRACKING

The surface burning and tracking which occurred is due to a concentration of surface leakage currents. When heavily contaminated insulator surfaces are moistened conducting electrolytes are formed and the surface resistivity is drastically reduced. Leakage current flowing over the surface may result in surface heating and the formation of localized surface sparking which, in turn, may produce more heating. If localized temperatures become high enough, the combination of the reduction in dielectric strength plus the gradient disturbance resulting from the leakage currents causes the sidewall puncture observed. This phenomenon appears to be a function of the design of the insulator. If local temperatures persist at a high level for a long time, the polymer is broken down and surface charing, burning or tracking results. This appears to be a function of the materials used.

MECHANICAL STRENGTH TEST

Several of the returned insulators were subjected to mechanical strength tests to determine whether the burning had in any way reduced the mechanical strength of the units. Eight of the most severely burned insulators were selected for this test. The average strength realized was 21,087 lbs. with a minimum of 16,450 lbs., and a maximum of 25,400 lbs. Fifty percent of the failures occurred when the terminal hardware failed. Rated strength of the insulators when initially made was 20,000 lbs., and only two units failed below this rating. The average strength of new units is about 24,000 lbs. While this would indicate that the burning had little effect on the mechanical strength, one must conclude that if the insulators had been allowed to remain in service indefinitely and burning had continued, the mechanical strength would have been more seriously affected.

DAMAGE BY RIFLE FIRE

The Boston Edison Company installed six 115 Kv GEPOL insulators on a double circuit 110 Kv steel tower line in May, 1964. These insulators were installed in an area which had been subject to heavy vandalism and damage by rifle fire. On October 26, 1964, the utility reported that all six of the insulators had been damaged by rifle fire. Typical damage is shown in the photograph Fig. 6. Ammunition found at the site was 22 caliber long Super X rim fire cartridges. There was also some possibility that larger ammunition might have been used, but no positive evidence of this was found at the site. All insulators were left in service and are operating without difficulty. Damage consisted of breaking the outer hoods.

LABORATORY DUPLICATION OF FIELD RESULTS

Prior to releasing the GEPOL insulators for field trials, a very extensive test program was carried out in the laboratory. [1 & 2] This test program was by no means confined to the usual tests for transmission line insulators and in all of the testing program, no failures occurred of the nature of those reported from the field trials. Additional tests have been run in the laboratory since the reported field failures. One has been developed that produced results very similar to the burning that has occurred in the field. It involves a jet of water applied on the top skirts of the insulator while a 60 cycle voltage is held on the insulator just under flashover value. By subjecting an insulator to this

test over a long period of time (usually in excess of an hour) the beginning of deterioration in the insulator surfaces can be detected. By continuing the test for several hours, the type of damage found on insulators returned from the field can be duplicated. Fig. 7 illustrates the damage on an insulator subjected to this laboratory test.

It is recognized that this test does not duplicate the contamination conditions to which the insulator is exposed in service, but it does provide one means of testing insulators to determine whether they can be so damaged, and this may serve as a useful tool in future development work.

CONCLUSIONS AND FUTURE PLANS

While only approximately one percent of the insulators which have been exposed to this sequence of field trials has exhibited evidence of tracking or surface burning, this performance would certainly not be acceptable for normal insulators. It is, however, encouraging to note that many of the exposure areas where no difficulties have been encountered are also contamination areas. One of these is on the Dallas Power and Light Company system in a 115 Kv substation adjacent to a cement plant. This was selected as an extremely severe exposure and three units have been in service there for over a year with no trouble. Another example is on the 69 Kv system of the City of Brownsville, where three 115 Kv units have been in service for approximately sixteen months with no trouble. In this application, the operators find it necessary to frequently wash porcelain insulators. The GEPOL insulators have not been washed.

The general result of this experience leads to the conclusion that while the GEPOL insulators in their present form are not suitable for general application, they are capable of fulfilling most operating requirements. Experimental work is currently in progress in the laboratory to determine whether modification in design or material will solve the problem. Laboratory investigations alone can not conclusively provide the required information. It is not possible to devise laboratory tests which reliably duplicate the wide variety of field conditions plus the time factors. It is proposed to repeat field trials under conditions which are now known to be most severe upon completion of favorable laboratory tests.

REFERENCES

"A Polymer Insulator for High Voltage Transmission Lines" F. S. Nichols and F. C. Vose, IEEE Conference Paper 63-1039.

"Some Characteristics of Polymer Insulators for High Voltage Transmission Lines" F. C. Vose, IEEE Conference Paper 64-36.

TABLE I - SUMMARY OF FIELD FAILURES

Company	Voltage Kv	Number Returned	Installed Date	Removed Date	No. Burned	No. Punctured	No. Not Damaged	Serial No.
Memphis Light, Gas and Water Division	115	6	March '64	Oct.'64	0	1	5	484, 486, 500, 506, 512, 514
Niagara Mohawk Power Corporation	115	6	May '64	Nov.'64	6	1	0	711, 713, 727, 729, 730, 737
Appalachian Power Company	138	1	Jan. '64	Dec.'64	1	1	0	282
Jersey Central Power and Light Company	230(2)	6	Feb. '64	Oct.'64	5	4	1	269, 272, 279, 281, 283, 288
Virginia Electric and Power Company	110	3	Oct. '63	Oct.'64	3	3	0	128, 130, 143
Tampa Electric Company	69	2	July '64	Jan.'65	2	1	0	300, 321
Houston Lighting and Power Company	69	1	July '64	Jan.'65	1	1	0	558
Indiana and Michigan Electric Company	138	3	Dec. '63	Jan.'65	0	1	2	274, 286, 290
		28			18	13	8	

TABLE II - SUMMARY OF ELECTRICAL TESTS ON RETURNED INSULATORS

Insulator Serial No.	Utility	Hoods Punctured by Hood Number	Wet Flashover Value (Kv)
130	Virginia Electric & Power Co.	1 through 8, 12	162
143	Virginia Electric & Power Co.	1 through 3, 12	245
128	Virginia Electric & Power Co.	1, 2, 12	293
711	Niagara Mohawk Power Corp.	1	253
713	Niagara Mohawk Power Corp.	0	311
727	Niagara Mohawk Power Corp.	0	377
729	Niagara Mohawk Power Corp.	0	380
730	Niagara Mohawk Power Corp.	0	311
737	Niagara Mohawk Power Corp.	0	393
269	Jersey Central Power & Light Co.	1	355
272	Jersey Central Power & Light Co.	11, 12	239
279	Jersey Central Power & Light Co.	10, 9	226
281	Jersey Central Power & Light Co.	12, 11	-
283	Jersey Central Power & Light Co.	12, 1	-
288	Jersey Central Power & Light Co.	0	342
500	Memphis Light, Gas & Water Div.	1	312
484	Memphis Light, Gas & Water Div.	0	382
486	Memphis Light, Gas & Water Div.	0	372
506	Memphis Light, Gas & WaterDiv.	0	375
512	Memphis Light, Gas & Water Div.	0	348
514	Memphis Light, Gas & Water Div.	0	380
282	Appalachian Power Co.	1 through 9, 12	123
274	Indiana & Michigan Electric Co.	1	-
286	Indiana & Michigan Electric Co.	0	-
290	Indiana & Michigan Electric Co.	0	-
300	Tampa Electric Co.	0	-
321	Tampa Electric Co.	1, 12	-
558	Houston Lighting & Power Co.	1, 12	-

Fig. 1. Insulator returned from Jersey Central Power and Light Co. damaged by leakage currents.

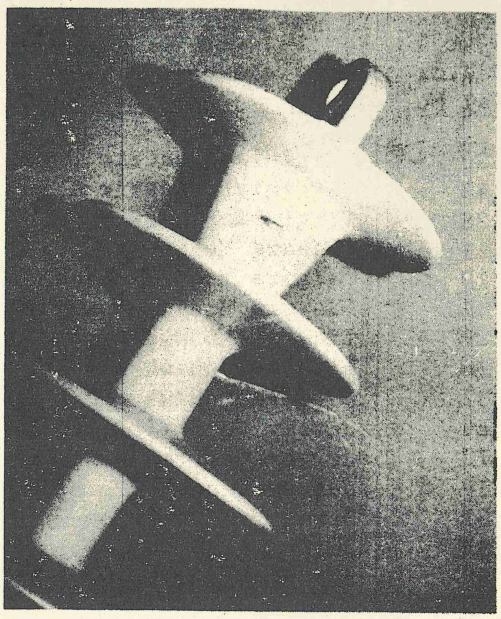

Fig. 2. Insulator returned from Indiana & Michigan Electric Co. damaged by leakage currents.

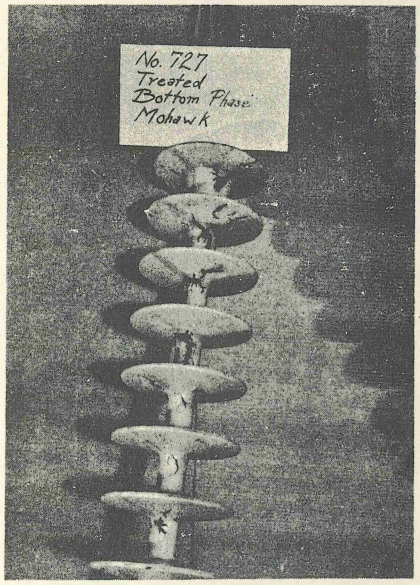

Fig. 3. Insulator returned from Niagara Mohawk Power Corp. having been in service with silicone grease coating damaged by leakage currents.

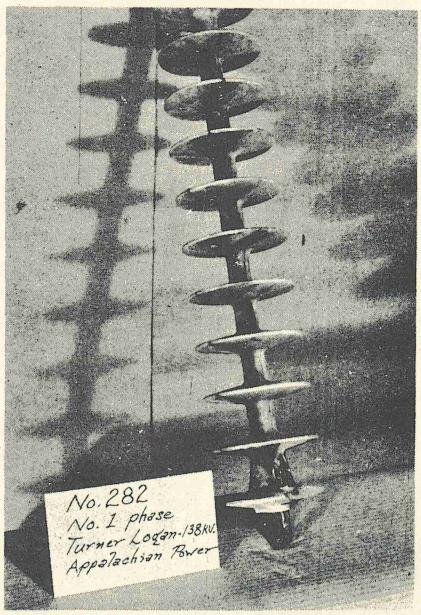

Fig. 4. Insulator returned from Appalachian Power Co. after flashover in service.

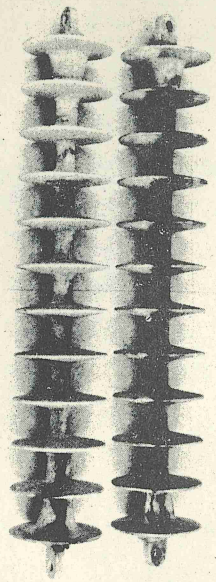

Fig. 5. Insulators returned from Tampa Electric Co. contaminated in service with heavy coating of phosphate and burned by leakage currents.

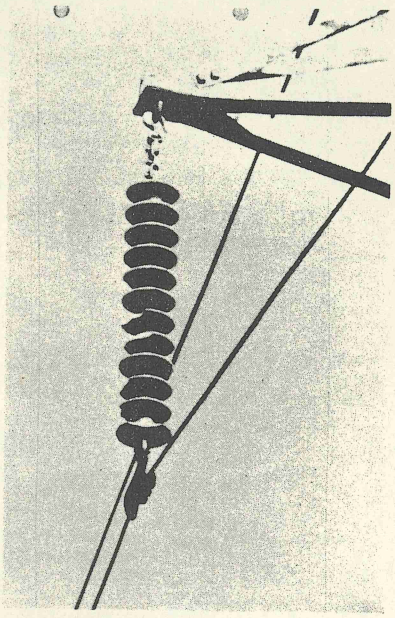

Fig. 6. Insulator on Boston Edison Co. system damaged by rifle fire.

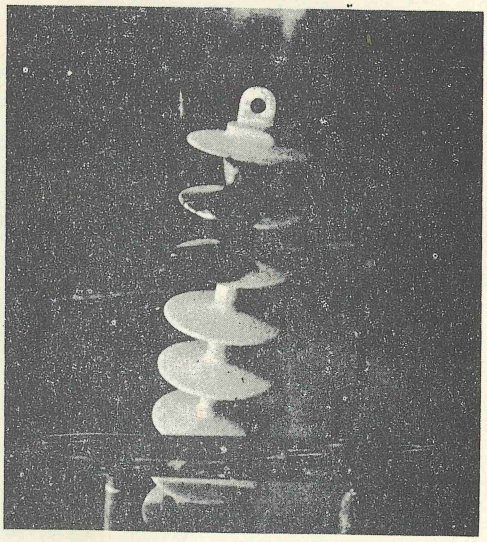

Fig. 7. Insulator damaged in laboratory test by special burning test with leakage current.

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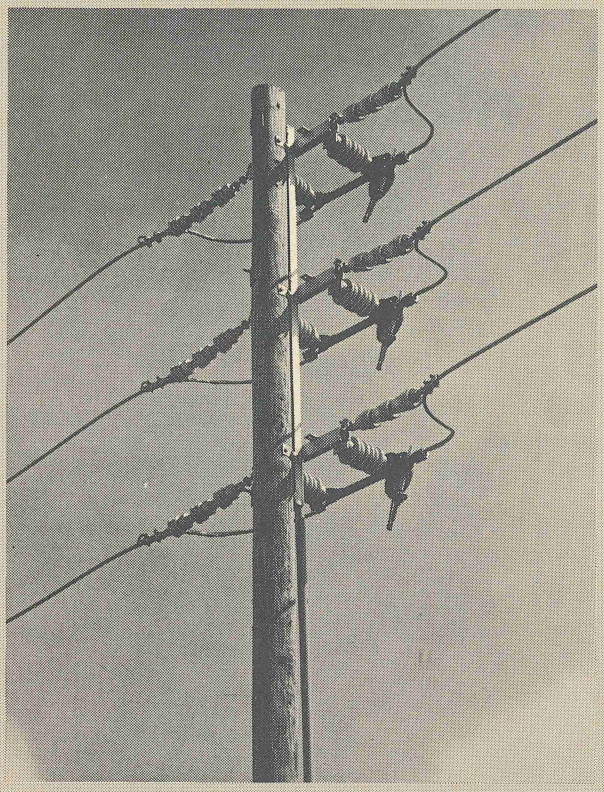
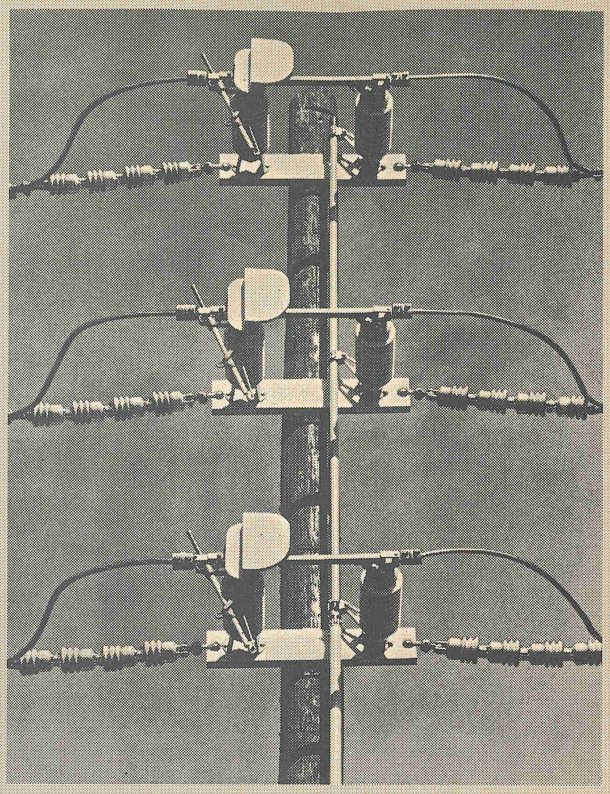
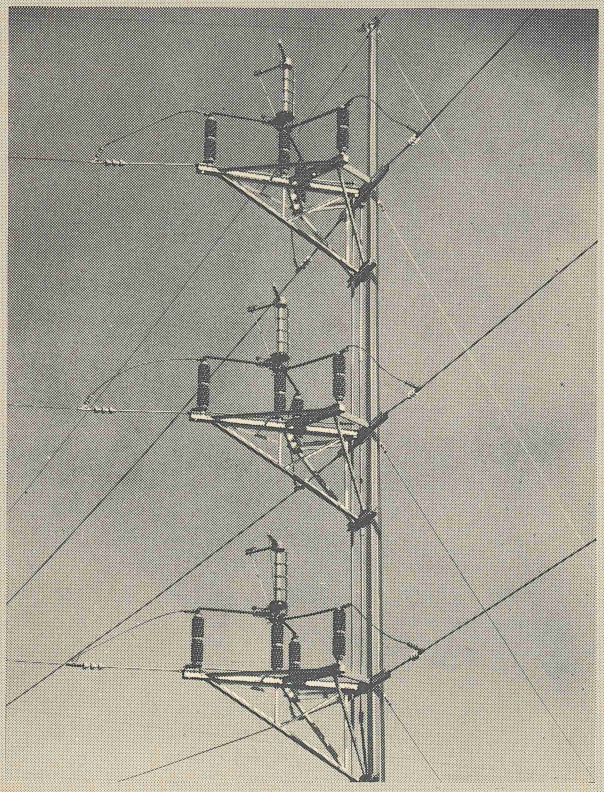


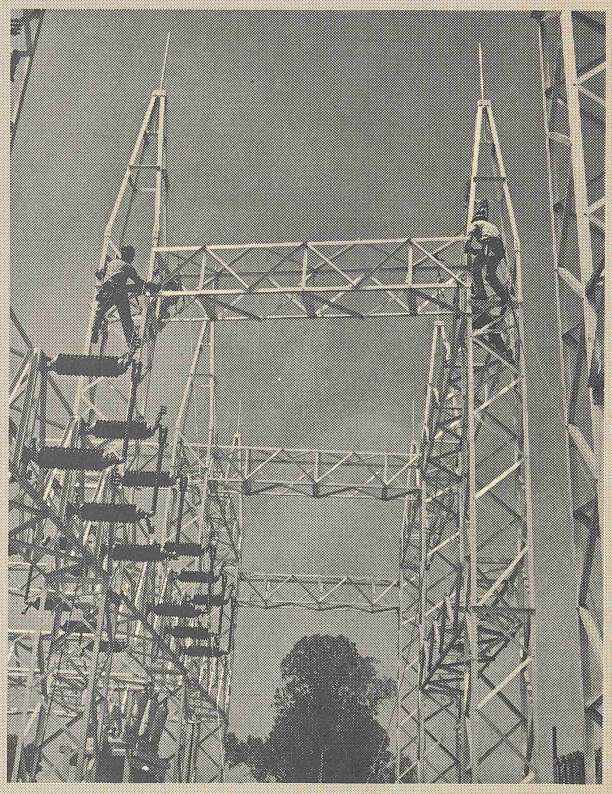
Chance 27 kv "D" Switch and Interrupter side-mounted on 3-phase aluminum support



Side-mounted phase-over-phase Chance 34.5 kv "DP" Switch with Saf-T-Gap expulsion Interrupter



115 kv, 3-way Chance GOABS with vacuum Monoruptr on a steel Unipole



Installation of Type "S" Side-break switches in a Chance aluminum substation

Make Copies & Send to:
~~Kaminski~~ -Frey- ~~Kingsbury~~
& ~~Hose~~,

The use of Fiberglas in the construction of transmission lines has increased in the last few years as new ways of using this material are being discovered.

I would like to tell you of several ways that we at Carolina Power & Light Company are putting it to use on our transmission lines.

Since it has such a high insulating value we are trying to use it to raise the impulse level of the structure by replacing certain parts of the structure with the Fiberglas.

For example, on one of our older 115 KV double circuit tower lines we wished to improve the lightning performance of the line by increasing the insulation, but were unable to add additional insulators because of the limited airgap clearance between the top conductor and the middle crossarm brace. This clearance limited the number of insulators that could be installed.

In order to increase the airgap we are in the process of replacing the middle crossarm brace with Fiberglas braces.

These braces are to be ordered with a turnbuckle in one end. The turnbuckle is for the purpose of allowing the brace to be delivered with the normal manufacturing tolerances as to length. Unless special procedures are used to obtain an exact length for the Fiberglas brace, the tolerances would be too large for the brace to be substituted for the metal brace on the arm. The turnbuckle provided a convenient means of adjusting the length to fit the tower. These braces cost about $12.00, and allow us to increase the number of insulators from 7 to 9. The replacing of the brace is done at the same time we reconductor the line.

On wood H-frame lines the same Fiberglas brace with built-in turnbuckle can also be used as outside knee braces to support the ends of the crossarm.

Since Fiberglas has very little compressive strength, it cannot be used as knee braces to strengthen the top of the structure against transverse loadings. For this purpose wood or other material must be used as the inside knee braces.

Our standard 115 KV H-frame line has 11½' of wood in series with the insulators. This extra wood insulation is obtained by using a flying tap type pole ground on an unbraced structure. When we add wood knee braces to strengthen the structure against transverse loadings, the wood in series with the porcelain is reduced from 11½' to 6', a reduction of 275 KV assuming wood adds 50 KV per foot at 4 M.S. flashover.

If we could substitute the Fiberglas braces for the wood knee braces then the wood in series with the porcelain remains unchanged at 11½'. This substitution can be made on the outside braces, but cannot be made on the inside braces when the top of the structure is to be strengthened for transverse loadings.

Since most of our braces are installed for transverse loadings we have not used Fiberglas as braces as we see no particular advantage in using both wood and Fiberglas braces on the same structure.

If we should need to support the ends of the arm against a heavy vertical load only, then we would use the Fiberglas brace as we do not reduce the insulation level of the structure.

We have recently completed a 115 KV single pole line, part of which has Fiberglas arms supporting the insulator strings and using 3 - 10" disc per string.

The use of the Fiberglas plus 3 - 10" disc enables us to save considerable pole height and gives a very pleasing appearance.

These arms are 5' in length and can be placed vertically on the same side of the pole or in a more normal triangular configuration. The spacing between the arms is 7'.

This installation is somewhat of a trial installation as we cannot be sure that 3 - 10" disc insulators will prevent tracking. We will know more about this as we gain more experience with this installation.

The 60 cycle wet flashover of the combination is 335 KV while the 4 M.S. positive flashover value is 1200 KV, which is about the same as our standard H-frame structure.

The line has been in operation for six months at this time in an uncontaminated atmosphere with no sign of tracking. We are hopeful that we can use more of this type of construction in the future.

In 1964 we purchased six G.E. Polymer insulators and installed them at different locations on our 115 KV system in order to gain experience.

As you know, these insulators are not normally used with porcelain in series and the question of tracking was largely unanswered at that time.

Sixteen months later, in 1965, one of these Polymer insulators flashed and caused a momentary operation of the O.C.B. This insulator had been installed in a contaminated area adjacent to a paper mill.

The insulator had tracking marks on the petticoats and the bottom end of the insulator skirts were blown off of the central core at the mold marks. The flash occurred partially over the insulator skirts at the top of the string and through the central core at the bottom end.

There was a ground fog condition at the time and it is supposed that the slight moisture condition initiated the flash. After the initial flash the insulator must have dried enough to restore the insulating value as the line stayed in service until the insulator was changed later the same day.

We have not purchased any more of these units and are waiting to see if the tracking problem can be eliminated. The addition of porcelain in the flashover path could help prevent tracking.

We are also using Fiberglas strain insulators in guys where necessary to obtain proper clearances between the guy and the conductors. Normally we do not use insulators in guys, but the Fiberglas strain insulator is ideal for increasing clearances when necessary.

We also use Fiberglas down lead brackets to support the flying tap pole ground wire on single pole structures.

The majority of our installations have consisted of the down lead brackets and guy insulators, but we are finding new uses for the Fiberglas.

We are considering using the Fiberglas as crossarm braces on single pole structures, but have not definitely decided to change from the conventional wood braces.

We are definitely interested in the possibilities of Fiberglas and would like to find new uses for it on transmission lines.

F. D. Jerome
10/5/66

FDJ:HH

EPOXY HIGH VOLTAGE INSULATORS FOR OUTDOOR USE

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For presentation at the Symposium

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INTRODUCTION

Insulators for outdoor use with high voltages have been available since before the turn of the century. These high voltage insulators must generally provide several basic functions:

1. Mechanical support with sufficient strength for the intended application.
2. Adequate dielectric strength for normal and surge overvoltages.
3. Adequate leakage distances which will make efficient use of the surrounding air medium.

Throughout the history of the electrical industry in the United States, wet process porcelain has served this need. What are the properties that an insulating material must have in order to fill the need satisfactorily today?

1. Dielectric strength
2. Mechanical strength
3. Impact strength
4. Light weight
5. Thermal shock resistance
6. Tracking resistance
7. Inertness to contamination and weathering
8. Easily cleaned surface
9. Quick, simple manufacturing processes
10. Economy

11. Reliability

12. Acceptable appearance

Porcelain is outstanding in a number of these areas, but falls short in several others. Its ultimate mechanical strength is usually far below the laboratory value for test bars, and is frequently only a few thousand pounds per square inch. Suspension insulators, of course, take advantage of porcelain's higher compressive strength by designs which put the ceramic portion of the suspension string in compression, rather than in tension.

The impact strength of porcelain is notoriously poor. In the United States this is of considerable importance, for the care which our linemen customarily give strings of suspension insulators is considerably less than desirable. Moreover, frustrated hunters and vandals with access to firearms use the insulators for target practice surprisingly often, with occasionally disastrous results.

The handling, storage and erection of increasingly heavy porcelain pieces, particularly necessary as the trend toward ever higher voltages proceeds with larger conductors and greater spans, makes obvious the need for lighter weight without loss of strength.

The problem of contamination in many areas remains a serious one today, particularly in industrial areas, along coastlines, and in misty, foggy conditions. The build-up of airborne deposits on the insulator in contaminated areas results in high leakage currents, short circuits, or burned wooden crossarms during damp periods.

Finally, as anyone who has ever toured a wet porcelain insulator factory knows, the manufacturing process is slow and in many ways an art, with raw materials of questionable reproducibility, and some forming steps still reminiscent of scenes from ancient Egypt. Very large pieces today are still difficult to make without excessive numbers of faults and losses in manufacturing. The slowness of the process has other effects, too, for it directly influences the quick delivery of special items and, thereby, the speed of service which today's customer expects.

EARLY GENERAL ELECTRIC STUDIES

In 1954 the General Electric Company began a program to study other materials which could overcome these deficiencies without sacrifice of porcelain's advantages. Though the thirteen years which have now elapsed appear to indicate little diligence was exerted, in fact this time was required because of porcelain's outstanding reliability. The failure rate of high quality wet process porcelain is essentially nil: even a fraction of one percent insulator failure rate in twenty-five years would be considered catastrophic by both vendor and customer. Furthermore, it was evident when we began our program that there was at that time a complete

lack of knowledge of the reliability of polymeric materials when exposed to the weather in high voltage applications. Finally, the market conditions for insulators for many of those years made it extremely difficult for the manufacturer to consider higher priced raw materials unless manufacturing techniques could be greatly simplified, and unless outstanding property improvements could be identified. The development of manufacturing processes thus became fully as important as selection of the right material, and long evaluation programs were needed for identification of the advantages of insulators from non-porcelain bodies.

By 1957 the search at General Electric had narrowed to epoxy and butyl rubber. All other contenders had failed in some essential property --- weathering, tracking, easy contamination, or poor electrical characteristics. Hundreds of formulations had been studied, but many more were to be studied even after the field was narrowed to these two materials. Interestingly enough, both butyl and epoxy are now sold for outdoor use by our company. The Insulator Department of the General Electric Company has developed and tested its proprietary epoxy based GEPOL® high voltage suspension insulators. This paper will concern itself with this epoxy development, pointing out only that the butyl formulations have also been developed for use on current transformers and potential transformers at the Meter Department, while the Distribution Protective Equipment Department has successfully developed and marketed a fuse cutout employing a molded butyl insulator.

For use in insulators both the butyl and epoxy formulations were generally found to require a central reinforcing member, which ultimately became a rod of fiberglass reinforced plastic. Although epoxy formulations of satisfactory strength could be developed which did not use the rod design, they inevitably were too brittle to withstand severe temperature cycling, usually cracking at low temperatures. Furthermore, the most satisfactory results at low temperatures were obtained only from flexibilized formulations. This flexibility also contributes significantly to the impact resistance of the units.

TRACKING AND EROSION

The most serious problem has been surface creepage tracking and erosion, and even now the problem is not completely solved for all cases. We presently believe that tracking is caused by surface scintillation that takes place across high resistance areas. Such high resistance areas are probably dry sections, under hoods for instance, or at different levels of contamination from neighboring areas. Scintillation occurs as tiny arcs close to the surface, and also as somewhat larger power arcs. Unless anti-tracking materials are used, the end result of this scintillation is carbonization, which forms a conductive path, leading to failure of the insulator. The need for an anti-tracking additive became obvious quite early and resulted in the now patented use of hydrated alumina. Although the action is not completely understood, it may be that the combined water in the hydrated alumina serves to oxidize the carbonaceous particles formed, and possibly the aluminum oxide acts as a catalyst to this reaction. It is apparent, in

any case, that hydrated alumina in high concentration has a beneficial anti-tracking action on both butyl and epoxy compositions.

The use of epoxy without hydrated alumina has frequently led to failure. One recent publicized failure was at a major southern United States utility which installed a number of 34 and 51-inch vertical epoxy-fiberglass insulator rods in series with five porcelain insulators on a 110 KV line. During wet conditions, the epoxy rods failed to provide the necessary primary insulation and shorted out. Experience in our laboratories has shown us that such systems which do not contain anti-tracking fillers are easily tracked by any of various tests.

Development of a satisfactory laboratory tracking test has been a problem. So far we have had our best laboratory correlation with visual field results by operating an insulator near its 60 cycle flashover voltage, while simultaneously spraying a water jet over the top skirts. This test, after several hours, gives damage similar in appearance to that experienced in the field, but does not always predict which material is superior to another. Other tests on samples of the insulating material, not in the form of an insulator, have given less correlation. We are continuing our studies on the development of a satisfactory laboratory test. Without such a test, we are constantly hampered by lack of correlation with field results. One of the chief problems with present laboratory tracking tests is that those which can be completed in a reasonable period of time use voltages which are well above normal operating voltages. Frequently the test voltages are at or near the flashover voltage, as in the test described above. These high voltages may give quick results, but it is questionable whether the results are related to failure mechanisms at lower voltages. Our latest studies are aimed at tests using voltages near the normal operating voltage, but at this time we have insufficient data to indicate success. The entire problem is one of many unknowns and deserving of close study.

69 KV SUSPENSION INSULATOR

In 1959 the first GEPOL epoxy insulators were prepared for field service. The design of this 69 KV insulator is shown in Fig. 1. The hardware at each end was bonded into place on the ends of a fiberglass reinforced polyester rod, about which the filled, flexibilized bisphenol-A epoxy was cast and cured. The nine skirts were molded integrally so that the central rod was completely covered. This avoided the well-known problems associated with tracking along exposed fiberglass. The design incorporated an overall diameter of seven inches, an arcing distance of thirty-one inches, and a leakage distance of sixty-four inches. The ultimate tensile strength rating was 15,000 pounds. In electrical characteristics, it was equivalent to a string of five porcelain ten-inch diameter suspension units.

A series of laboratory tests was run on these insulators. Some of the tests were in accordance with the American Standards Association Standard C29.1. Others were devised especially for these polymer units, for it is

necessary to realize that some of the standard tests are meaningless for polymer, and some properties of polymers would not be tested by using only the porcelain tests.

Sixty cycle wet and dry flashover tests and positive and negative impulse flashover tests on one, two, and three units were made. The results are compared to porcelain in Fig. 2. Note the consistent advantages of polymer over porcelain in each test.

Time-load tests were begun which five years later indicated that a continuous 9,000 pound load did not cause deterioration mechanically or electrically.

Impact tests were carried out in several ways. The most interesting were on a rifle range using .22 calibre (Fig. 3) and .30/06 ammunition (Fig. 4), from a distance of fifty feet. None of this treatment resulted in mechanical failure of an insulator, though it was possible with direct hits to knock off portions of the polymer. On porcelain insulators where the hardware is quite close together, if the porcelain shell is broken the flashover voltage can be drastically reduced. The loss of hoods on the polymer insulators, however, has relatively little effect on the flashover voltage, because the hardware is still separated by considerable distance. A subsequent tensile test of the insulator which had been struck several times by .30/06 fire directly on the fiberglass rod produced failure at 20,100 pounds --- in the hardware!

High current tests were carried out on the polymer insulators at 8,500 amperes for four cycles by short circuiting a fuse wire on the surface. No damage was observed. A similar test of 7,000 amperes for four cycles on a porcelain unit blistered the glaze surface. The glaze on porcelain, of course, is important in contamination resistance.

1959 FIELD TRIALS AND RESULTS

In the fall of 1959, the 69 KV units were put into service in the northeastern United States on both 69 and 525 KV lines; at Baltimore, Maryland, in the mid-Atlantic section of the country on 115 KV service; and in the southeast on 69 KV service on the Florida coast. This range of sites was expected to give a series of climatic conditions and some variation in contamination, particularly in Florida, where the insulators were within a few hundred feet of the surf. All were in constant use, except for the 525 KV case. In this one trial, the insulators were on an experimental EHV line and were deenergized from time to time as other unrelated experiments were carried out.

In 1964, five years after the field trial began, some of the Florida insulators were returned to our laboratories for examination. No signs of electrical, mechanical, or chemical deterioration could be found. The tests for chemical deterioration included thermogravimetric analysis,

differential thermal analysis, and infrared analysis of aged and new samples of actual insulators. Electron micrographs of sections of the insulators also revealed no visible differences. Some calculations were made on the possibility of shortened insulator life because of electrophoresis, which is the phenomena of migration of particles in a liquid due to a potential difference between immersed electrodes. The question had arisen whether fillers and other dispersed materials might slowly move through the cured epoxy resin, which was viewed for this purpose as a highly viscous liquid. The conclusion reached was that electrophoresis alone would not be an important factor in shortening the life of the insulators.

In 1966 a storm resulted in heavy salt deposit on the remaining Florida insulators, all of which were in the vertical position, and shortly thereafter the units repeatedly flashed over, tracked, and were removed from service.

In late 1966 one unit at Baltimore, in a vertical position, was found to have a very slight amount of tracking after seven years of service, but it is still in use at this time. Seventeen others are completely unchanged at this location, except for one which has been slightly chipped by rifle fire.

The units in the northeast are all still serving satisfactorily without problem at this time, after nearly eight years of service.

115 KV SUSPENSION INSULATOR

It was decided in 1963 that sufficient data was available to justify further trials. This decision was based on both field experience with the 69 KV design, and also on laboratory tests of new designs. In this new design the fiberglass of the central rod was given looped ends which directly hooked over ears on the hardware, and the hardware was partially embedded in the cast flexibilized skirts (Fig. 5). It was believed that this new rod would give direct mechanical load transmission without the need for hardware adhesives. In addition, the polyester portion of the rod was replaced by epoxy. Replacement of the polyester was expected to reduce the problem of different coefficients of expansion at interfaces. Electrical and mechanical tests in the laboratory on a 115 KV insulator with these modifications indicated outstanding performance. This forty-one inch long unit (Fig. 6) was rated at 20,000 pounds strength, had twelve hoods, and was equivalent to a string of seven ten-inch diameter porcelain units in leakage and arcing distances. Some of the typical electrical and mechanical characteristics of the polymer unit are compared to the ratings of a string of seven porcelains in Fig. 7.

1963 FIELD TRIALS AND RESULTS

In this 1963 field test approximately seventeen hundred units were

manufactured and put into service at more than sixty utilities scattered throughout the United States. Many of the utilities intentionally chose their most difficult locations for the test, either high contamination or high vandalism areas. In particular, coastal and industrial areas were chosen which were known to be especially severe service areas for porcelain. Many of these areas require frequent cleaning of porcelain insulators, or heavy and frequent applications of silicone grease.

Field damage data began to trickle in after about six months in the shortest cases, and has been collected continuously right up to the present. Interestingly enough, it was observed after several years that most damage came during the fall or early winter. Perhaps periods of drought which occurred in the United States during those summers allowed contaminants to build up without washing off, and then misty fall weather brought on scintillation and tracking damage.

The damage which so far has occurred in the 1963 field trial has tended to fall into several patterns. There may be either an initial puncture through the sidewall to the hardware near the first hood at either the ground or conductor end of the insulator (Fig. 8), or there may be isolated signs of surface tracking at any of various locations on the insulator. In many cases the puncture type of damage has not been associated with any further tracking in the time elpased to date. Inasmuch as the voltage is non-linearly distributed along an insulator, with the ends of the insulator carrying a disproportionately high percent of the total, the punctures through the sidewall to the hardware are explainable, especially when contamination reduces the overall insulation level. Punctured porcelain suspension insulators drastically reduce or eliminate the value of the insulator because of the short distances between the cap and the pin. The polymer insulators, however, appear to be capable of still carrying line voltages long after puncture occurs. Often even the flashover voltage is not greatly reduced by a puncture through the sidewall.

The worst damage at any site is always caused by tracking and erosion. In a few cases near heavy industrial contamination this has become quite spectacular, with tracks burnt down far enough into the polymer to expose the fiberglass (Fig. 9). It is worth repeating, however, that even these severely eroded insulators have not caused line drops to occur.

No examples have ever been found of damage occurring straight along the fiberglass rod from one end to the other, nor have any mechanical failures occurred, such as disintegration of the hardware adhesive or fiberglass rod failure.

As an example of the above, it may be enlightening to examine in some detail the results of one GEPOL field trial in Brownsville, Texas. Brownsville is located in the extreme southernmost tip of Texas, near the Gulf of Mexico. It represents one of the most severe coastal contamination areas in the United States. To make matters even worse, in one area the local utility serves a large chemical plant with a loop power line which is parallel

to the Brownsville ship canal. Dredging of the canal produces a great deal of salty soil which is piled alongside the canal. Winds pick up this soil and salt and deposit them on the insulators nearby. More than three hundred GEPOL insulators were used at this site.

With conventional porcelain insulators, the result of this contamination problem at Brownsville is crossarm fires. Although the fires are frequently extinguished before the crossarm is completely destroyed, the arm is severely weakened and needs replacement. In order to reduce the problem of contamination, the porcelain insulators are frequently coated with silicone greases. The GEPOL units have never been cleaned, coated with grease, nor given any sort of special attention, yet continue to appear amazingly free of contamination.

As mentioned earlier, the initial damage which occurs is usually in the form of a puncture through the sidewall to the hardware, as shown in Fig. 10 for a Brownsville insulator. In this case the puncture has occurred at the ground end, between the first and second hoods, directly through the polymer sidewall to the hardware. In other cases, the puncture has come at the conductor end of the insulator. Subsequently, tracking may occur, as shown in Fig. 11, leading away from the original puncture. To date, the damage shown is the most severe at the Brownsville site. The test is continuing and will be examined periodically. The polymer insulators have never had a crossarm fire, and have never been given any special attention. Although some damage to some insulators has occurred, the overall view is that they are serving at least as satisfactorily as the porcelains, quite possibly more so.

By 1966, when all the GEPOL sites were considered together, it was observed that although the incidence of failure of several percent for those units in the vertical position was too great to be tolerated, no problem occurred in insulators in the horizontal position, in either the 1959 or the 1963 tests. For reasons which are not fully known but likely are due either to self-cleaning after contamination or to altered electrical fields, or a combination of both, the horizontal position is very significantly less subject to damage than the vertical position. Unfortunately this correlation did not become clear until 1966, by which time some utilities had removed all polymer insulators from use regardless of whether damage had occurred to every insulator, so that our data is somewhat reduced. Careful searching of all records and examination of the hundreds of insulators still in service continues to show no failure of horizontal units.

This phenomenon has had an interesting effect at one large installation in the southeastern United States. This particular trial of the 1963 units, the most extensive conducted at one site, involved a ten-mile 100 Kv line with one side of each tower using porcelain insulators and one side using GEPOL insulators. More than four hundred GEPOL insulators were used in this one experiment. Results by 1966 were as noted above --- some failures in the vertical position, but none in the horizontal. Late in 1966, all the vertical units were replaced by porcelain, inspected, and the undamaged

insulators transferred to new locations in a horizontal position. Fortunately an unusually high number of units were originally in the horizontal position and have continued in these locations, giving us a large sample of unmoved insulators to observe in the future.

1965 FIELD TRIAL

In 1965 one very limited new experiment took place. By this time the cycloaliphatic epoxy resins had been in existence for a few years and gained some claimed popularity for outdoor experience. A limited number of 115 KV cycloaliphatic resin-based units were produced and put on trials in one industrial area of the eastern United States and in England. The results were quite poor. Although the formulation had shown outstanding laboratory tracking performance, the insulators failed in a few weeks in field use.

A major appraisal was obviously called for in the General Electric insulator program. The cycloaliphatic was still believed superior, and happily a formulation was found to solve the rapid field deterioration problem. The market was studied and it was concluded that the somewhat limited use of transmission insulators in the horizontal position did not justify marketing polymer units for that single purpose at that time. In addition, the higher voltages were felt to be increasingly harder to service, though no positive evidence was available. A survey of the market indicated one attractive area --- the strain distribution insulator. These strain, or horizontal, units are used widely in 15 KV and lower voltage service.

15 KV STRAIN INSULATOR

A new product was designed. This 15 KV strain insulator is twelve inches long, with seven hoods (Fig. 12). It eliminates the encapsulated hardware design and, instead, incorporates bonded hardware similar to the original 69 KV units of 1959. The bonding has been modified, however, in that a wedge design is used to provide a positive mechanical interlock, should the adhesive ever fail to bond properly (Fig. 13). This unit replaces two conventional ceramic units for 15 KV service. Units were put into 15 KV service in 1966 on the east coast and are performing well after nearly one year's service. Since February, 1967, this insulator has been widely sold in the United States.

The 15 KV strain insulator, therefore, represents the marketing culmination of thirteen years of research and development of polymer materials, designs, and processes for high voltage outdoor insulators. Hundreds of formulations, dozens of designs, and nearly two thousand insulators for field testing were required to achieve this accomplishment.

What are the properties and advantages of this insulator? Typical mechanical and electrical data are shown in Fig. 14, compared to the code requirements for 15 KV service. As an example, the wet flashover value is thirty-three percent greater than that required by the code. Other advantages, compared to porcelain, are:

1. Approximately seventy percent less weight and volume --- reducing shipping, warehousing, and construction costs. Fig. 15 shows an equivalent number of GEPOL and porcelain 15 KV deadend insulators being carried.

2. Extremely high impact strength --- reducing losses in handling and from vandalism. Fig. 16 shows there is no damage to the GEPOL insulator, even when it is struck violently with a hammer.

3. Simplified installation --- requiring only one man instead of two needed for porcelain.

4. Flexibility of design.

5. Simplified manufacturing processes. Production of a GEPOL unit from raw material to finished insulator requires about one day, compared to several weeks for porcelain.

6. Improved appearance. Fig. 17 compares the appearance of horizontal porcelain and GEPOL units on the same pole.

PLANS FOR TRANSMISSION INSULATORS

Work is still continuing at our laboratories on transmission units for 69 KV, 115 KV, and higher service. Changes from the designs used in 1959 and 1963 are being studied in the laboratory, and are based on circumvention of the damages encountered in the field trials. In particular, we feel the embedded hardware, though it contributed significantly to the mechanical strength, caused electrical puncture problems and must be redesigned. Questions have also been raised about the shape of the hoods, particularly the sharpness of their periphery and whether this causes unnecessary nonlinear voltage distribution stresses. We plan to put more units into the field in large numbers in the next year or two. At this time we anticipate that horizontal service will be the first successful use of these units, but even this must be proved by considerably more field experience than we now have available at these high voltages.

OTHER OUTDOOR INSULATOR APPLICATIONS

Although the major emphasis in this development program has been on insulators for distribution and transmission lines, some other quite interesting applications have been studied, tested, and, in some cases, sold.

Fig. 18 shows an experimental pin type insulator which has been serving in 12.5 KV service in an extremely contaminated area in Texas for three years. This is the same Brownsville site where the 115 KV insulator test was carried out, near the Gulf of Mexico. As in the case of the 115 KV GEPOL suspension insulators, none of these pin types has been associated

with a crossarm fire, a result which has greatly impressed the utility.

Fig. 19 shows a radio antenna guy insulator with an ultimate strength of nearly one million pounds. It weighs six hundred pounds, replacing two porcelain insulators weighing together three thousand pounds. The weight saving advantages can be tremendous when it is realized that many radio towers use scores of the porcelain insulators.

In 1964 the Power Switchgear Department of the General Electric Company built three 500 KV air-blast breakers, one of which is shown in Fig. 20. The insulators for the current transofrmer stacks are fifteen feet long, with an inside diameter of three feet, and an outside diameter of forty-four inches. The size of these monolithic units was considered greater than could be achieved in porcelain. The Insulator Department was successful in manufacturing thirteen such pieces in epoxy without losing a single piece, although the size was larger by far than any previously made in our polymer shop. The great compressive loads and internal pressures necessitated the use of a tubular core of fiberglass reinforced epoxy, about which was cast the flexibilized track-resistant encapsulation. Nearly five thousand pounds of material was used in each casting. Subsequently the casting was machined to form the skirts, and then assembled in the 500 KV breaker. These air-blast breakers have been in use nearly two years at this time, and are serving without problem. The interest in such parts continues high for it is now possible through their use to eliminate the fear of catastrophic failure. Any damage to a porcelain unit could cause cracks to propagate throughout and disintegrate the unit. The strength of the fiberglass core in this new polymer design would undoubtedly keep the breaker in place, however, even if a cannon shell scored a direct hit and pierced the column through both sides. We have prepared a number of such housings for other size breakers in the last year, and expect increasing EHV applications.

Smaller vacuum interrupter housings (Fig. 21) have also been manufactured and placed in use. Fig. 22 shows a stack of nine of these units being installed in the field. In this case, the small module makes it possible to build stacks of any desired height without concern for weight and strength requirements. No problems have arisen in this application, and several hundred have been sold to date.

Bushings on transformers are also being made from epoxy. Shown in Fig. 23 is a "SEAL PAC"^{TM} transformer with epoxy bushings, compared with an earlier transformer of equal rating. This unit is remarkable for its small can size and unobtrusiveness in service. One of the more severe tests of this new transformers has been made at a seaside test site in Texas, where excellent results have been obtained under drastic contamination conditions.

One final application of interest is the use of epoxy coatings in outdoor high voltage electrical applications. The covers of distribution transformers mounted on poles have always provided a perch for wildlife, such as squirrels. Unfortunately, if the squirrel's tail should brush

against a high voltage lead-in wire at the same time that his claws scratch through the paint on the cover of the transformer, the results are fatal for both the squirrel and the electrical service. Several years ago General Electric developed an epoxy coating which would provide a thick, insulating, essentially unscratchable surface, which could also be colored to meet the sky-gray color preferred by utilities. The coating can be rapidly applied by powder coating methods, such as the fluidized-bed technique. This insulating coating has had widespread acceptance and success.

CONCLUSIONS

A number of other applications are presently under study in our laboratories. Each one requires special attention to design to take advantage of epoxy's attributes, a manufacturing study for economy, and extensive field testing before it can be judged successful. From the broadest view, we believe that after a long, frustrating and frequently rocky road, the opportunities are now opening up for polymers in outdoor high voltage applications. It is neither technically sound nor economically wise today to exchange polymers for porcelain in every exterior high voltage application. Each one must be evaluated on a cost basis, market acceptance determined, extensive laboratory study pursued --- and then large doses of patience swallowed while field trials slowly bring in the final verdict on long-term reliability, still any polymer's biggest unknown.

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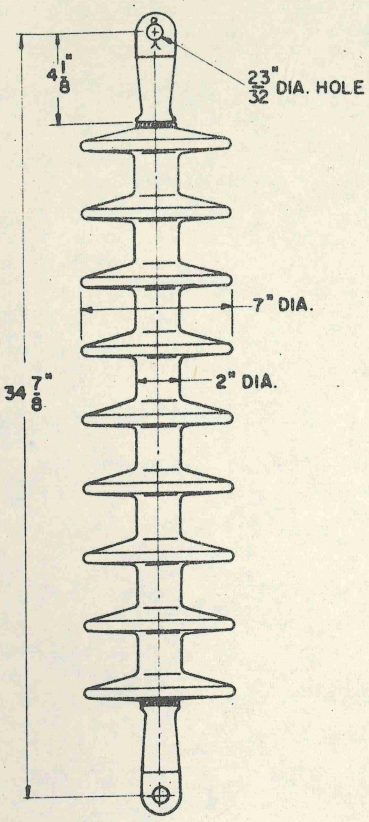

FIG. 1 --- 69 KV POLYMER SUSPENSION INSULATOR

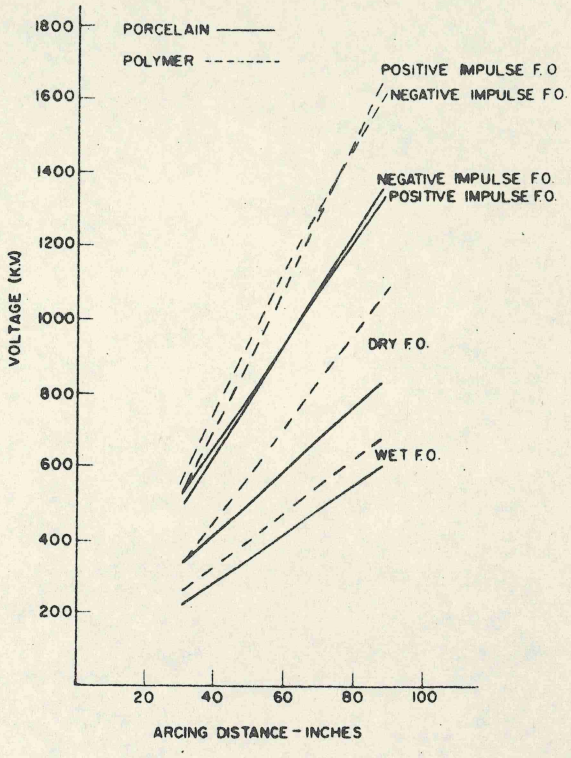

FIG. 2 --- A COMPARISON OF THE ELECTRICAL CHARACTERISTICS OF POLYMER INSULATORS WITH RATED VALUES OF PORCELAIN SUSPENSION INSULATORS 10" IN DIAMETER, 5-3/4" SPACED

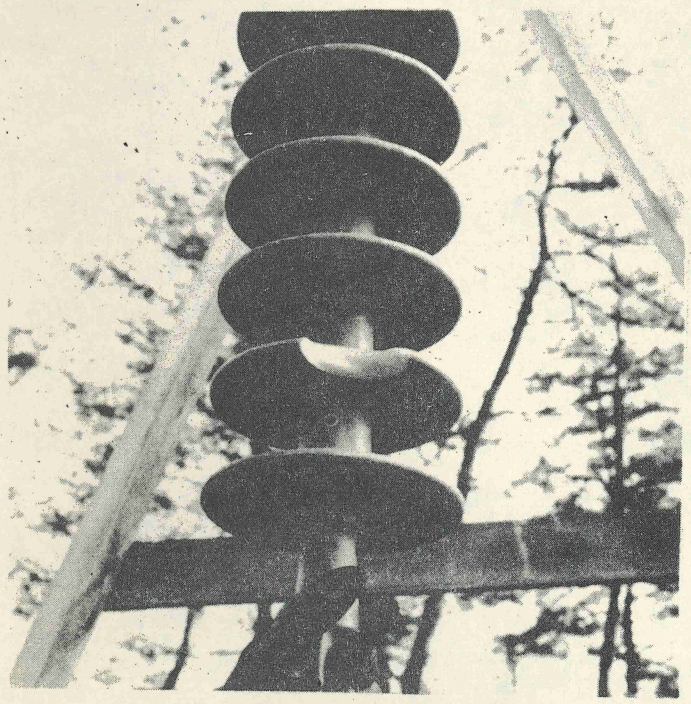

FIG. 3 --- .22 CALIBRE RIFLE DAMAGE

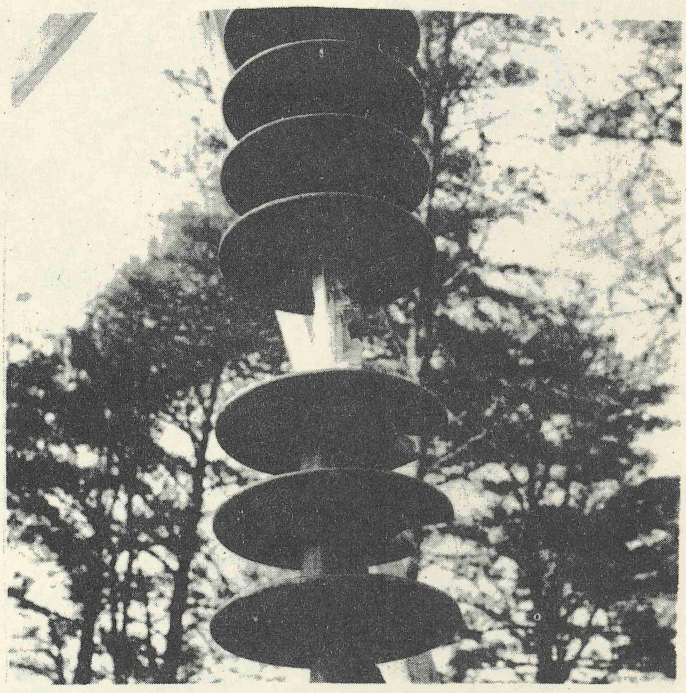

FIG. 4 --- .30/06 CALIBRE RIFLE DAMAGE

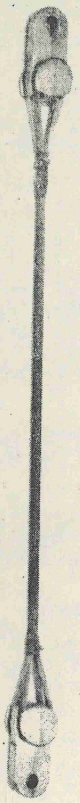

FIG. 5 --- 115 KV POLYMER SUSPENSION INSULATOR ROD DESIGN

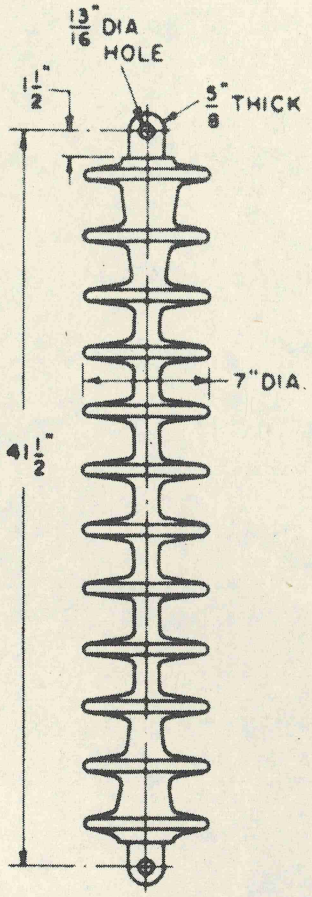

FIG. 6 --- 115 KV POLYMER SUSPENSION INSULATOR

CHARACTERISTICS	115 KV POLYMER SUSPENSION INSULATOR	RATING OF STANDARD 7 UNIT STRING SUSPENSION INSULATORS 5-3/4" x 10"
SIXTY CYCLE FLASHOVER, DRY, KV	462	435
SIXTY CYCLE FLASHOVER, WET, KV	352	295
IMPULSE FLASHOVER, POSITIVE, KV	730	695
IMPULSE FLASHOVER, NEGATIVE, KV	683	670
R.I.V. (Microvolts at 80 KV)	150	500

FIG. 7 --- COMPARISON OF THE CHARACTERISTICS OF THE 115 KV POLYMER INSULATOR WITH A STRING OF SEVEN PORCELAIN INSULATORS

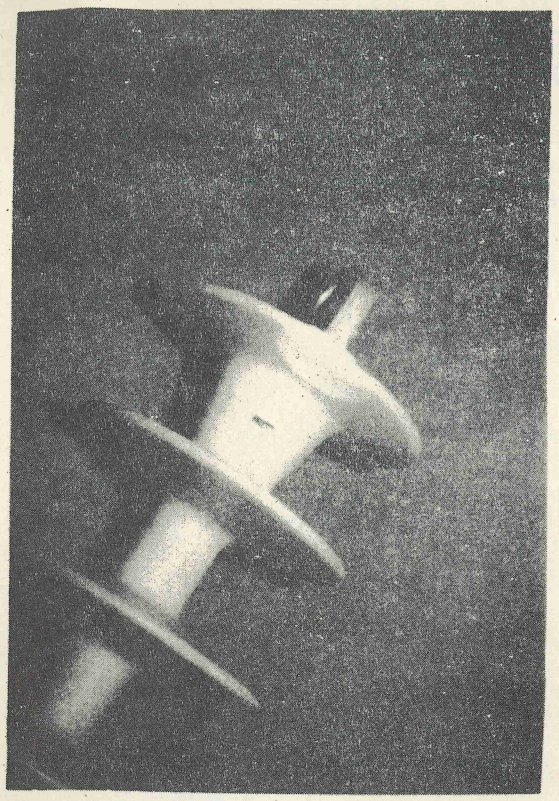

FIG. 8 --- PUNCTURE THROUGH SIDEWALL TO HARDWARE

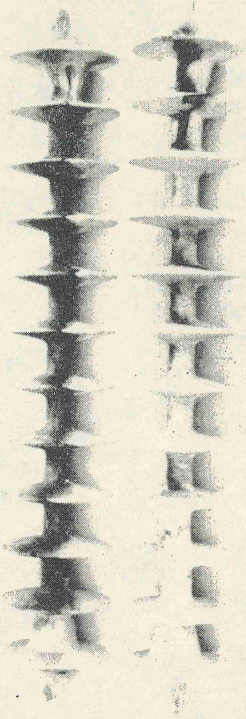

FIG. 9 --- SEVERELY TRACKED AND ERODED 115 KV POLYMER INSULATOR

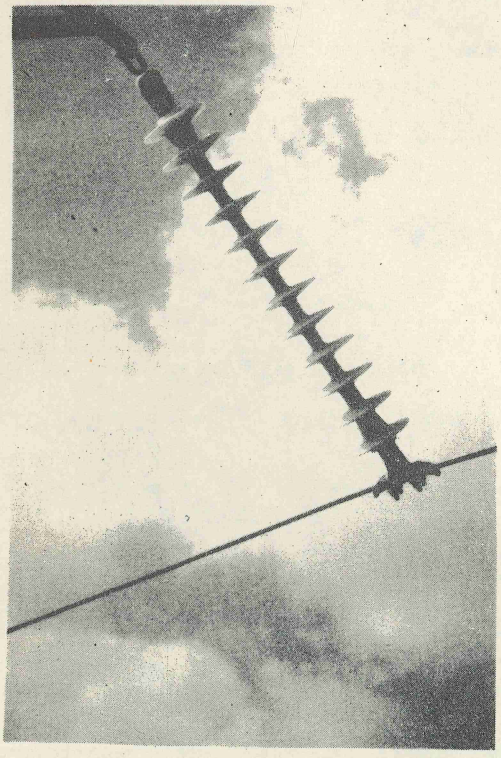

FIG. 10 --- INITIAL INSULATOR PUNCTURE AT BROWNSVILLE, TEXAS, SITE

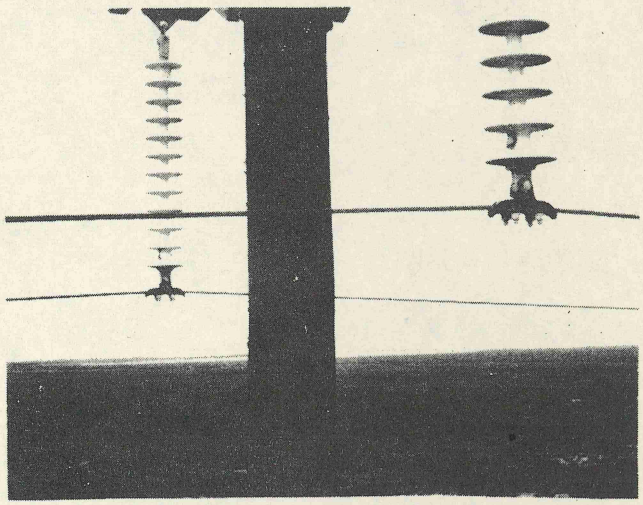

FIG. 11 --- BROWNSVILLE, TEXAS, INSULATORS SHOWING GREATEST DEGREE OF TRACKING TO DATE

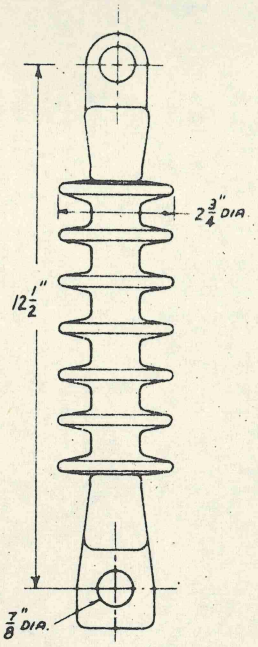

FIG. 12 --- 15 KV POLYMER STRAIN INSULATOR

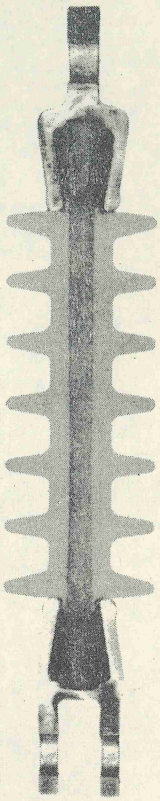

FIG. 13 --- 15 KV STRAIN INSULATOR WEDGE DESIGN

	GEPOL INSULATORS	15 KV SYSTEM
Leakage distance, inches	14	12
Dry arcing distance, inches	8¼	6¼
R.I.V. test KV RMS to ground	15	15
R.I.V. Max. Microvolts at 1000 KC	50	100
Impulse F.O. voltage, KV, Pos.	140	130
Impulse F.O. voltage, KV, Neg.	165	155
Low Frequency F.O. voltage, KV, Dry	100	80
Low Frequency F.O. voltage, KV, Wet	60	45
Low Frequency Puncture voltage, KV	150	115
Impact strength, inch-pounds	Virtually Indestructible	—
Net weight, pounds	3¼	—

FIG. 14 --- TYPICAL MECHANICAL AND ELECTRICAL DATA FOR 15 KV POLYMER INSULATOR VERSUS CODE REQUIREMENTS

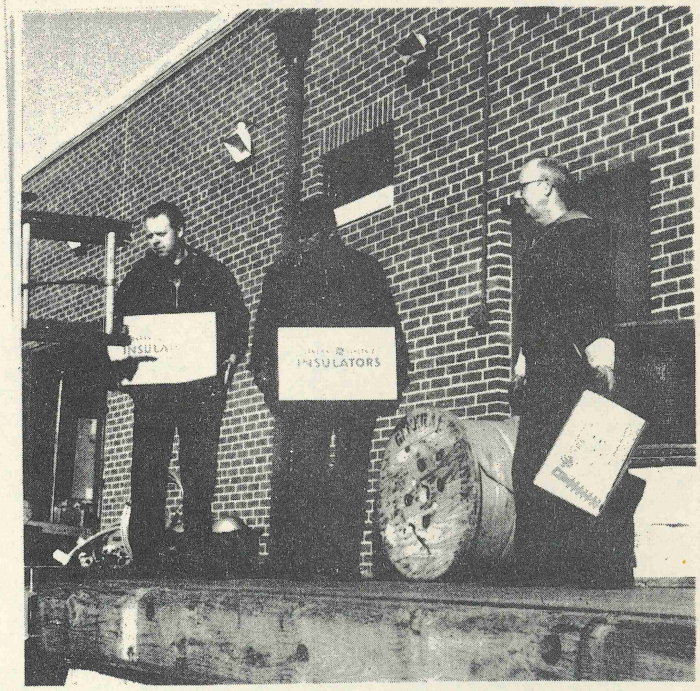

FIG. 15 --- COMPARISON OF HANDLING EASE OF POLYMER AND PORCELAIN INSULATORS

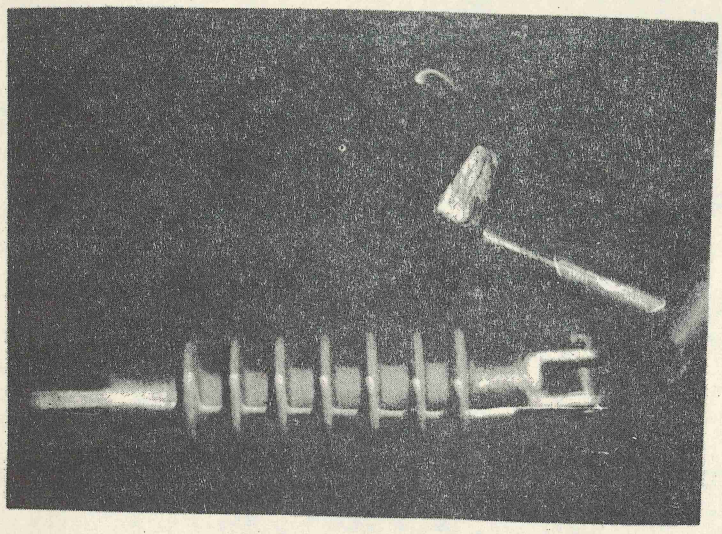

FIG. 16 --- DEMONSTRATION OF POLYMER INSULATOR'S HIGH IMPACT RESISTANCE

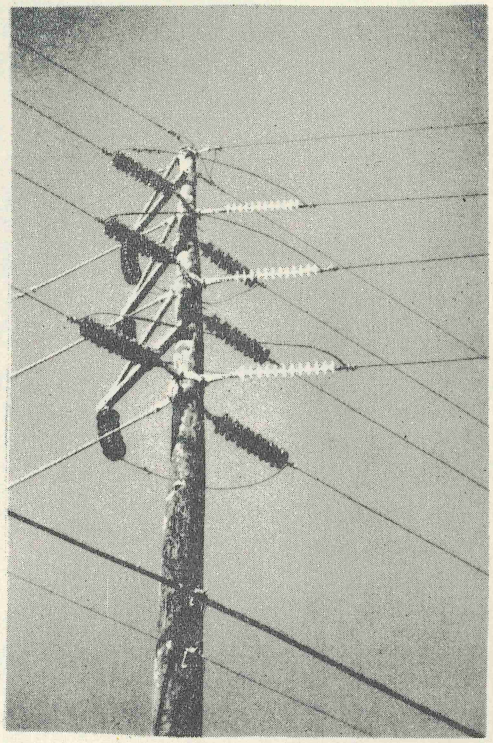

FIG. 17 --- COMPARING APPEARANCE OF PORCELAIN AND POLYMER STRAIN UNITS

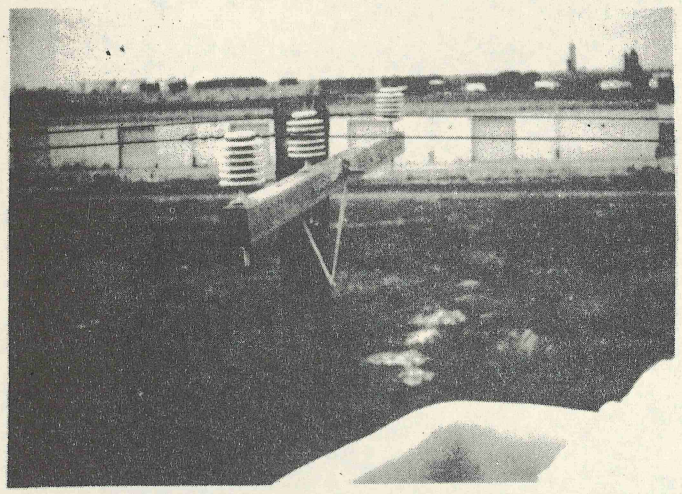

FIG. 18 --- 12.5 KV POLYMER PIN TYPE INSULATOR

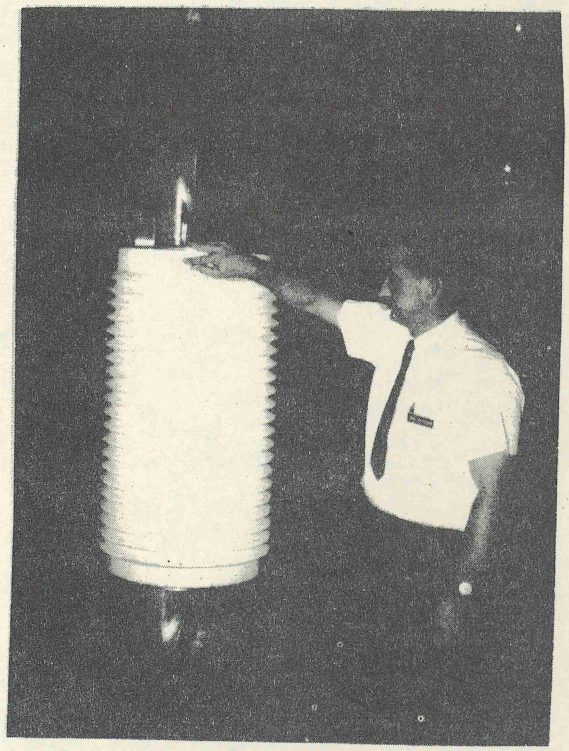

FIG. 19 --- POLYMER RADIO ANTENNA GUY INSULATOR

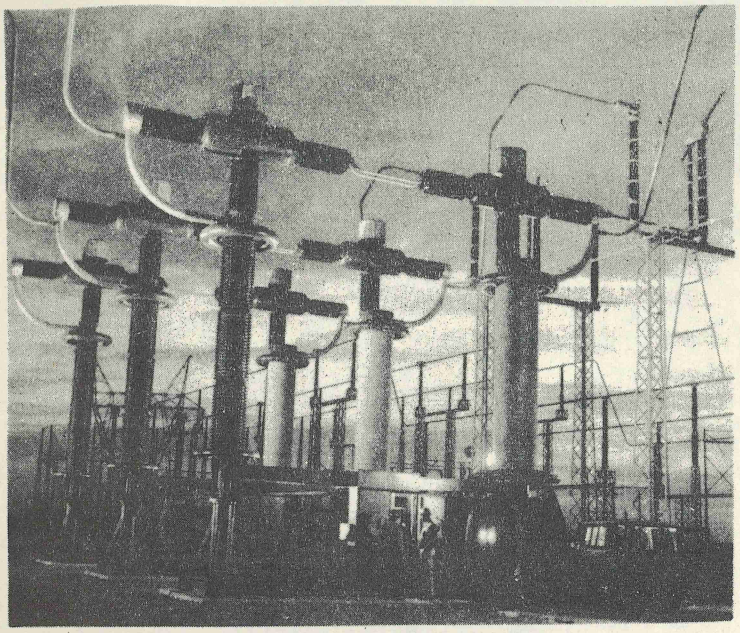

FIG. 20 --- 500 KV AIR BLAST BREAKER WITH 15 FT. POLYMER INSULATORS

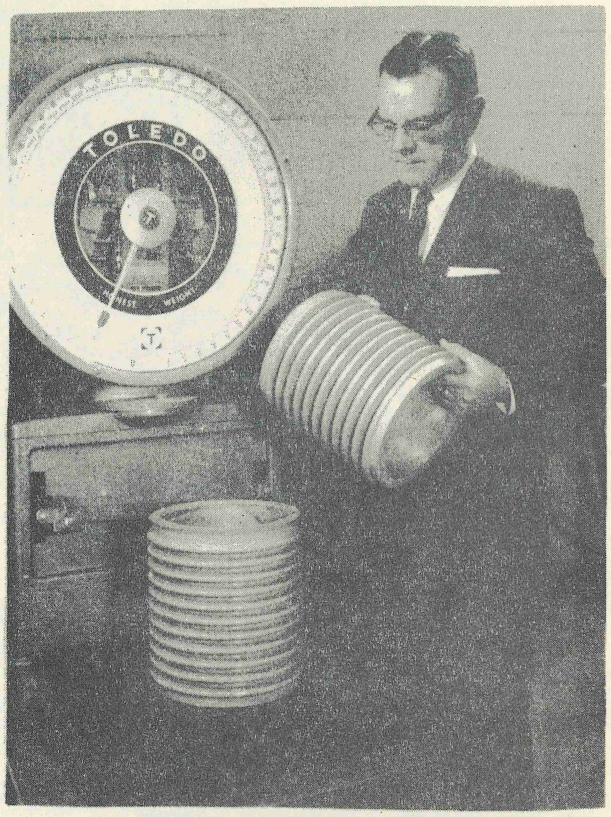

FIG. 21 --- 230 KV POLYMER VACUUM INTERRUPTER HOUSINGS

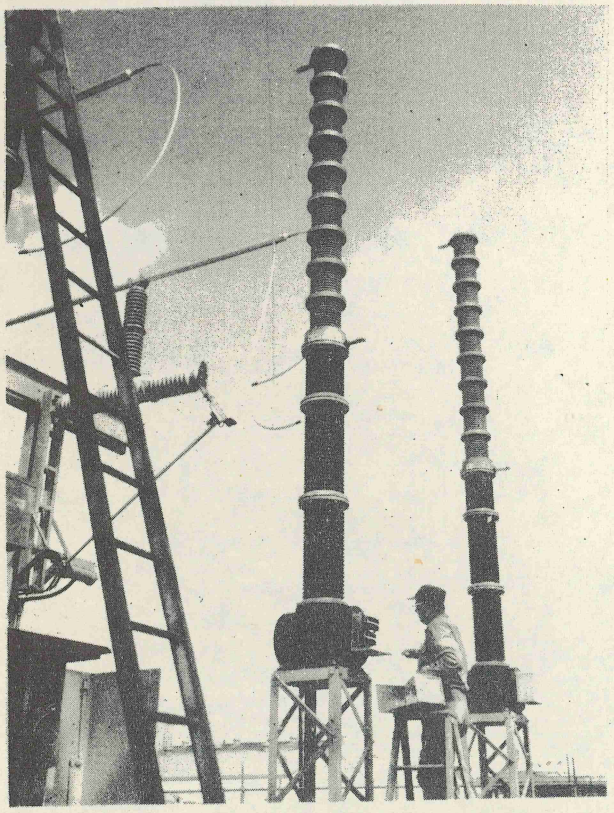

FIG. 22 --- STACK OF NINE POLYMER VACUUM INTERRUPTER HOUSINGS BEING INSTALLED

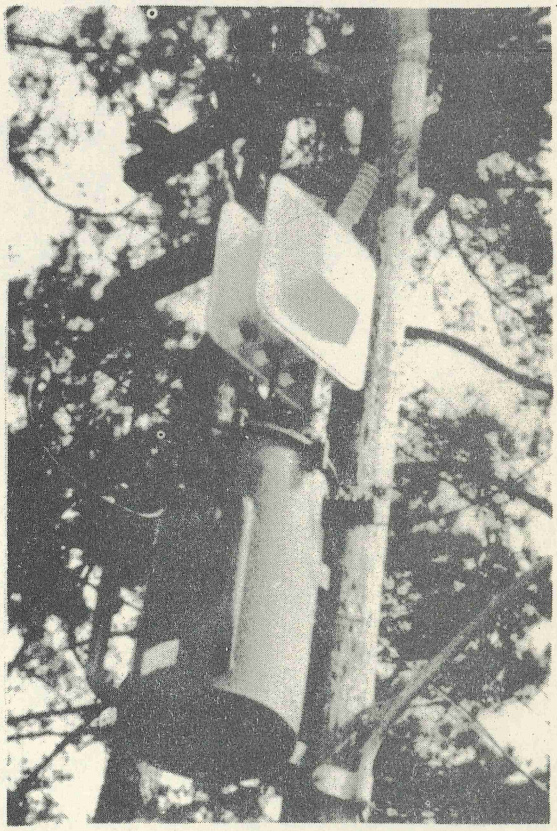

FIG. 23 --- 25 KVA TRANSFORMERS. NOTE EPOXY BUSHING ON TOP TRANSFORMER

with which it can make a bilateral schedule change; it is desired to balance out for total inadvertent in each area; if the algebraic sum of all inadvertent around the interconnection is or can be made zero, full balance between areas can be achieved; and, if it is not or can not be made zero, then there is a residual amount of inadvertent that is uncorrectable, and the equitable thing to do is to distribute it among all areas in proportion to their size.

The suggested technique is for all areas, at regular and previously stipulated times and for previously stipulated periods, to reset their net interchange schedules to eliminate their respective inadvertent accumulations during the stipulated period. This would be done universally and regularly, on a system-wise basis, at hourly or other time intervals, and for stated time periods which could even be the full hour. To the extent that areas can respond to these reset schedules, inadvertent accumulations would be corrected.

If the algebraic sum of all inadvertents were indeed zero, as several of the discussers suggest it would be, then the algebraic sum of schedule offsets would be zero, and frequency would not be influenced as inadvertent accounts were being automatically reduced to zero. If it turned out that the algebraic sum of inadvertents were not zero, then there is an uncorrectable residual inadvertent. The algebraic sum of schedule offsets would not be zero, and a small frequency deviation would develop, sufficient to spread the uncorrectable accumulation uniformly among all areas in proportion to their bias settings.

To simplify matters for system operators, and to avoid confusion with normal interchange schedule settings, separate setting dials could be used for the inadvertent correction setting. In each case it could be calibrated directly in terms of the inadvertent accumulation to be corrected, with appropriate allowance for the stipulated time allocated to the correction. Suitable megawatt constraints and frequency limits within which the corrections would be effective could be applied.

It is recognized that the suggested technique would require regularly scheduled concerted setting action on the part of all areas. Perhaps operating areas would not regard this as a greater burden than system-wide concerted resetting of frequency schedules for time error correction, particularly since the inadvertent accumulation correction action would be taken at regular times on a universal system-wide programmed basis.

In closing, I again wish to thank the several discussers for their thoughtful and penetrating comments.

References

[1] B. Littman and T. S. Chen, "Simulation of Bull Run supercritical generation unit," *IEEE Trans. Power Apparatus and Systems*, vol. PAS-85, pp. 711–722, July 1966.

[2] J. Adams, D. R. Clark, J. R. Louis, and J. P. Spanbauer, "Mathematical modeling of once-through boiler dynamics," *IEEE Trans. Power Apparatus and Systems*, vol. PAS-84, pp. 146–156, February 1965.

[3] R. R. Walker and W. H. Baker, "Control response of once-through steam generators," presented at the 1966 IEEE Winter Power Meeting.

[4] D. J. Ahner, C. E. Dyer, F. P. deMello, and V. C. Summer, "Analysis and design of controls for a once-through boiler through digital simulation," *Ninth Nat'l Power Instrumentation Symp., ISA Proc.* pp. 11–30, May 16–18, 1966.

[5] A. A. Ward and R. L. Stubbins, "Control testing on rapid load changes of the supercritical boiler at Alamitos Steam Station Unit 5," presented at the 1966 ASME Winter Annual Meeting.

Concept and Analysis of Epoxy–Ceramic Insulation System for Overhead Lines

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***Abstract*—A new insulation system for overhead electric lines is presented, together with the system concept and analysis of testing and development data upon which specific designs and application of epoxy–ceramic assemblies (ECA) have been based. For the purposes of data presentation and application referral, the discussion is directed principally toward transmission voltages of 69 kV and above. However, the system presented applies to the lower voltages as well.**

Present Problems and Needs

THE NEED for improved and more sophisticated insulation techniques for overhead systems is becoming increasingly apparent as the problems of "beautility," reliability, right of way, higher voltages, and underground are brought into focus in practical and economic relationships. The ECA insulation system is proposed as a major step toward fulfillment of such needs by providing shorter arm lengths and shorter suspension insulator string length.

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In many situations, the most realistic alternative to heavy investment in new overhead or underground facilities and right of way is the upgrading of the existing overhead plant to higher capacity through conversion to higher voltages. Of prime consideration in such ventures is the preservation of existing right of way boundaries, the appearance of the converted structures, and the adequacy of the line insulation to give satisfactory performance.

Traditional overhead construction consisting of wood–porcelain or steel–porcelain combinations has a long history, but it has not been without its problems. Pole fires, crossarm burning, and uncertainties in impulse levels and insulation coordination have caused greater spacings and more insulation to be provided than might otherwise be required.[1] With voltage levels gradually increasing over the years, overall economic and practical considerations indicate the necessity for departures from former practices.

The search for new insulating materials and techniques for overhead line construction has been going on for several decades. Until recent years, however, the lack of sufficient and accurate information regarding the performance characteristics of conventional construction has slowed the efforts toward a more sophisticated insulation system.[2]

Overhead line construction and insulation techniques now seem to be entering a new era. Vastly increased testing facilities,

coupled with stepped up industry effort in field and laboratory research, has yielded a substantial amount of information which heretofore had been unknown or uncertain and thus covered by conservative design or the educated guess.

Of principal importance in this new era is the emergence of plastics and their increased use for electrical insulation in such items as cable, cable terminations, transformers, and pole framing assemblies. The concern for the tracking phenomena associated with organic materials has diminished as application limits have been developed and field experience has increased.

ECA Insulation System and Concept

The ECA insulation concept is based on the premise that if a designated amount of ceramic material is normally required in conjunction with a wood or steel supporting member in traditional overhead construction, then a lesser amount of ceramic may be used with a supporting member made of an improved material having improved electrical characteristics; further, when the electrical characteristics of an improved insulating assembly can be accurately determined, reproduced, and maintained in an overall system of insulation coordination, then the added margins which have been traditionally inserted to cover unknown or contingent factors may be reduced or accounted for in part by the improved supporting member rather than the ceramic material.

One such improved material is presented here: a tubular member made of fiberglass strands, bonded by an epoxy resin, formed around a polyurethane foam core, and cured by a special process. It has demonstrated a strength-to-weight ratio as good as steel and has high resistance to tracking, corrosion, moisture absorption, and contamination. When such a member, with its high tensile and flexural strength, is properly combined with the high compressive strength and electrical properties of ceramics such as glass or procelain, the result is an ECA with attractive possibilities as a combination mechanical–electrical unit in overhead system pole framing.

Four ECAs are depicted in Figs. 1–4. These assemblies will be discussed in the following.

Selection of ECA Components

The plastic and ceramic components of ECAs are selected on the basis of wet 60-Hz insulation requirements derived from upper and lower limits of maximum switching surge values. The epoxy component is then adjusted in length to provide the required impulse and spacings.

Insulation strength at 60 Hz has been established as being slightly higher than switching surge strength under wet conditions, and surge values, together with lightning considerations, have been the dominating factors in determining insulation requirements. Maximum switching surges are generally considered to be in the area of 2.5 times normal line to ground voltage, or below that value for most occurrences with upper and lower extremes on the order of 4.0 and 2.0, respectively.[3],[4]

Using these values as upper and lower limits, together with 2.5 and 2.25 as reasonable medians for most occurrences, and a multiplier of 1.10 for withstand to CFO, Table I has been constructed, showing the number of $5^3/_4$- by 10-inch suspension insulators corresponding to the CFO for the various per unit surges. All values are crest under wet conditions. The nominal voltage has been increased by a multiplier of 1.05 on the upper limit, columns (1) and (2), as a customary upper operating range; and it has been retained on the derivations in columns (3) and (4).

By matching the CFO values of columns (1), (2), (3), and (4) to the crest value of the 60-Hz wet flashover of suspension insulators in series, the number of insulators set forth in columns (5), (6), (7), and (8) is obtained. Thus, some reasonable upper and lower limits of 60-Hz insulation are established, which are used in determining the amount of epoxy and ceramic components for ECAs.

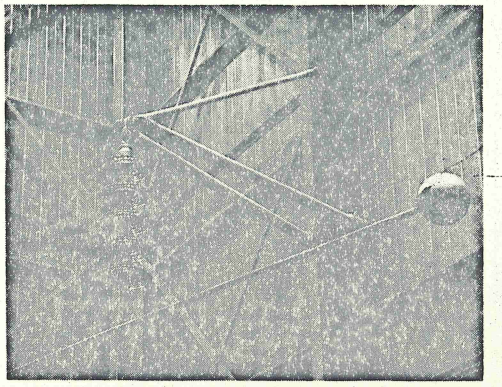


Fig. 1. Six-foot ECA crossarm with five suspension insulators. Electrical characteristics: 60-Hz flashover—714 kV dry, 431 kV wet. Impulse flashover—1174 kV positive, 1255 kV negative.

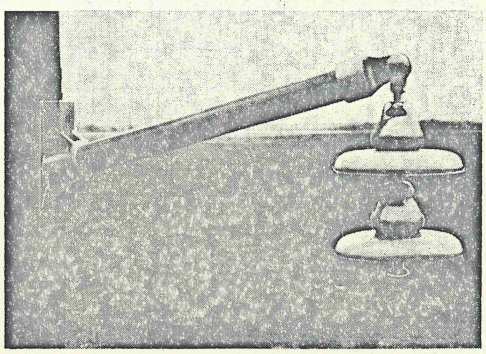


Fig. 2. ECA suspension unit intended for application at voltage up through 69 kV. Electrical characteristics: 60-Hz flashover—268 kV dry, 213 kV wet. Impulse flashover—456 kV positive, 601 kV negative.

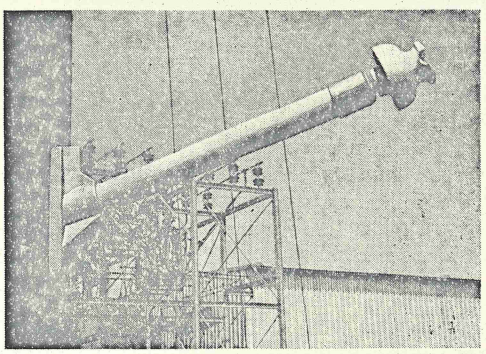


Fig. 3. Standoff type ECA for service through 34.5 kV. Electrical characteristics: 60 Hz flashover—283 kV dry, 162 kV wet. Impulse flashover—436 kV positive, 493 kV negative.

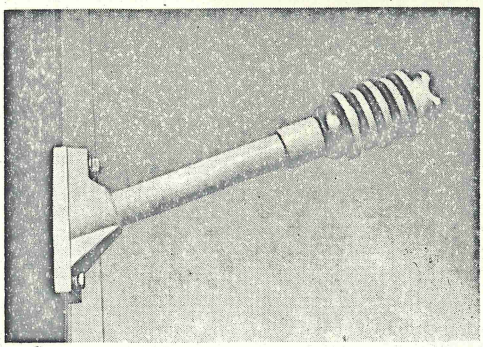


Fig. 4. ECA unit with suggested upper limit for application, at present, of 46 kV. See Fig. 8 for electrical characteristics.

TABLE I

60-Hz Insulation Requirements Based on Upper and Lower Surge Criteria—Clean Wet Conditions

Voltage Class, kV	CFO Based on Per Unit Surges, kV (1) 4.0 p.u.	(2) 2.5 p.u.	(3) 2.25 p.u.	(4) 2.0 p.u.	$5^3/_4 \times$ 10-inch Suspension Insulators Required to Meet CFO (5)	(6)	(7)	(8)
					Insulators Corresponding to (1)	(2)	(3)	(4)
69	260	162	139	124	4.3	2.6	2.2	1.9
115	435	270	234	207	7.3	4.5	3.8	3.3
138	522	324	279	248	8.9	5.3	4.5	4.1
161	610	378	326	290	10.4	6.3	5.3	4.7
230	870	540	466	414	15.4	9.2	7.7	6.9

Notes: 1) Columns (1) and (2), CFO = $\frac{\text{kV class}}{\sqrt{3}} \times \sqrt{2} \times 1.05 \times 1.10 \times$ p.u. surge.

2) Columns (3) and (4), CFO = $\frac{\text{kV class}}{\sqrt{3}} \times \sqrt{2} \times 1.10 \times$ p.u. surge.

3) All CFO values are crest.

The ceramic component of ECAs is selected on the basis of the lower limits set forth in columns (4) and (8), and the epoxy component on the basis of an overall combined strength equal to or exceeding the upper limits set forth in columns (1) and (5).

In other words, the ceramic component satisfies reasonable minimum to normal 60-Hz wet operating requirements and the combined epoxy–ceramic assembly provides sufficient 60-Hz strength for upper limits which may or may not be encountered.

Table I, line 4, and Fig. 1 represent an example of such a selection of ECA components. For selection of the ceramic units based on switching surge occurrences in the area of 2.0 E_{L-N} as a reasonable lower limit, the CFO [column (4), line 4] is 290-kV crest. Using this figure as the required 60-Hz wet flashover crest, it will be found from ASA rated string flashover values that 4.7 (say 5) insulators are required.

Using the same reasoning applied to the upper limit [column (1), line 4], 610-kV crest in wet flashover is required for the complete assembly, and this corresponds to the crest value (431 kV $\times \sqrt{2}$) of the wet flashover shown with Fig. 1.

The same analysis is applied to other voltage classes to determine the basic ECA components. Factors indigenous to local area conditions and practices may then be applied to increase or decrease the basic requirements.

For application in generally clean atmospheres, however, the selection of the basic ECA components according to the requirements of Table I has usually provided a unit which satisfied the impulse and other considerations as well.

In the lower subtransmission and distribution voltages, considerations for climbing space, appearance, impulse, and utilization of existing ceramic units may be the heavier influencing factors in the selection of ECA components.

A noteworthy observation in Table I is the close parallel between the number of insulators set forth in column (5) and those generally used in traditional construction practice. This indicates a total reliance on the ceramic insulation for all probable conditions in conventional application, whereas in reality the actual conditions may be considerably less severe, as represented in columns (6), (7), and (8).

Performance Testing and Analysis

The key to the successful development of the ECA insulation system lies in the choice of materials for use in conjunction with the ceramic component of the system. While many organic materials might fulfill the necessary requirements on a short-time basis, the selection of a material which will withstand the sustained effects of continuous electrical stress under various atmospheric conditions is limited. As standard dielectric tests are of a routine nature, they will not be discussed in this paper. Typical values are given in Figs. 5–8.

The projected application of an ECA insulation system required that the concept be demonstrated to withstand the effects of the continuous application of 60-Hz potentials, particularly under adverse conditions. Therefore, a test program was developed which, together with actual full-scale field installations, would determine the feasibility of the proposed ECA concept. The results of this investigation can be considered in three separate categories: laboratory tests of the glass reinforced epoxy component and laboratory and field tests of ECAs.

Laboratory Tests: Epoxy Component

The epoxy–fiberglass material which is utilized as a component of the ECA system has been, prior to its new application, a prime constituent of Chance Co. hot line tools. During the many years of successful application in this area, considerable technical information was accumulated relating to the electrical and mechanical properties of this material. In the beginning, very little information was available concerning the effects of sustained voltages over extremely long periods of time, since hot line tools are only energized for relatively short periods of time. It was thus necessary to conduct a thorough investigation of this area.

A variety of tracking evaluation tests have been developed within the industry; all have merit, but most are somewhat limited as to the dimensions and shape of specimen they will accommodate. An adaptation of a test developed by the Research Division of the Hydro-Electric Power Commission of Ontario provided a convenient means of evaluating the relative tracking characteristics of the glass reinforced component of the ECA insulation system.[5] These are shown in Fig. 9 and Table II. In addition, tests were also performed with an adaptation of the ASTM dust and fog tracking test.

The results of the tracking tests verify the findings of other researchers in establishing the high track resistant properties of the epoxy family. In particular, the specific epoxy system as used in ECA devices was compared with other available systems and was found to be as good or better than other popular systems now being used for electrical applications. However, no exact correlation exists between any accelerated tracking test and any specific set of field operating and environmental conditions. When exposed to a sufficiently high surface current discharge environment for an extended period of time, the epoxy member of the ECA system will track. The design of the ECA units is such as to minimize this possibility.

Laboratory Tests: Complete ECA Units

Since the findings from the tracking wheel tests alone could not be relied upon for the development of a successful integrated ECA unit, a test for full-scale prototype assemblies was devised. Sample ECA units were subjected to a test which was a modifica-

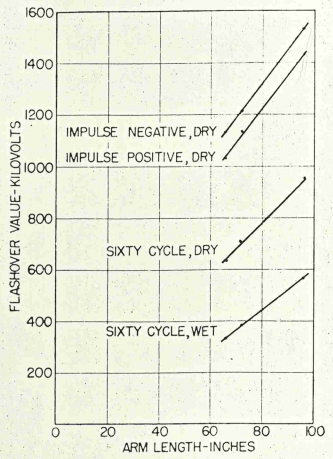


Fig. 5. Impulse and 60-Hz flashover values of several ECA crossarms. All tests conducted with five suspension insulators. Data corrected to standard atmospheric conditions.

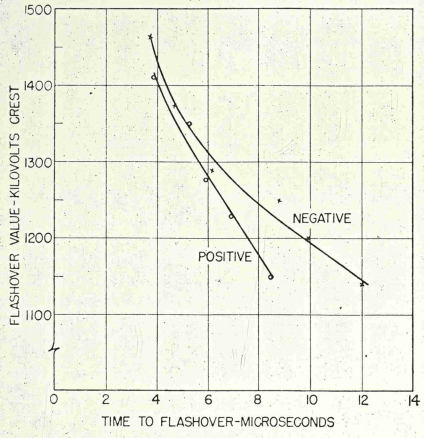


Fig. 6. Volt–time characteristic for 66-inch ECA crossarm with five suspension insulators. Data corrected to standard atmospheric conditions.

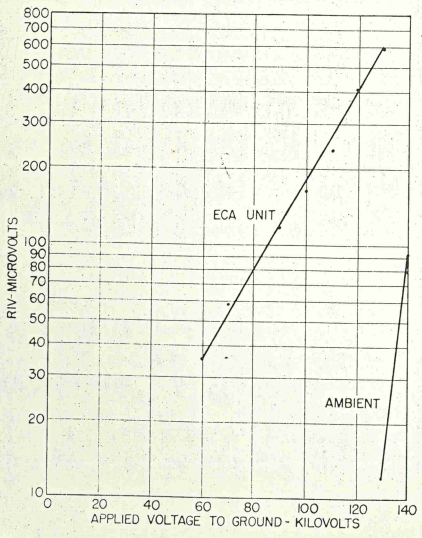
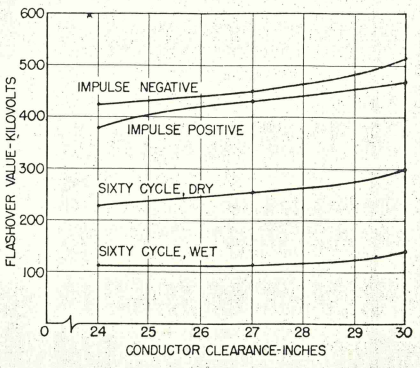
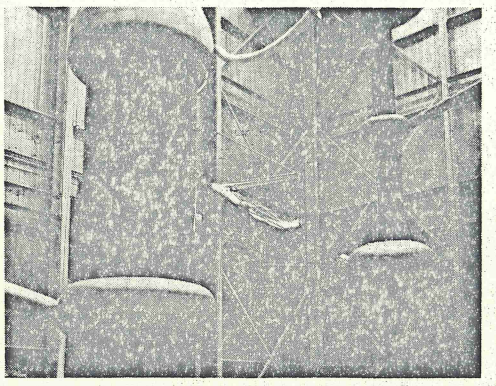


Fig. 7. Radio influence voltage characteristic of 72-inch ECA crossarm with five suspension insulators at 1000 kHz.



(a)



(b)

Fig. 8. (a) Impulse and 60-Hz flashover values for ECA units of type shown in Fig. 4. Data corrected to standard atmospheric conditions. (b) ECA crossarm undergoing 60-Hz flashover test.

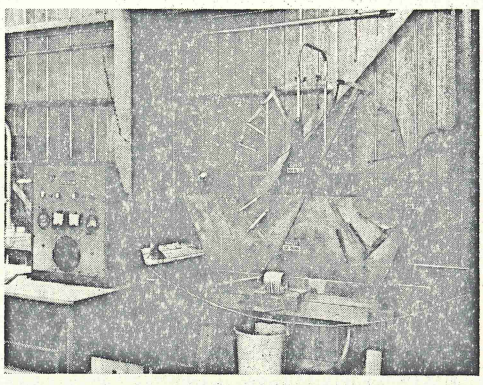


Fig. 9. Tracking wheel for study of relative tracking resistance of insulating materials.

TABLE II

RELATIVE TRACKING CHARACTERISTICS OF SEVERAL MATERIALS AS TESTED ON THE TRACKING WHEEL SHOWN IN FIG. 9

Material	Test Duration to Failure, hours
Spruce, coated with cellulose acetate butyrate	3
Glass-filled polyester	5
Epoxy system for ECA, uncoated	20
Epoxy system for ECA, coated	60

tion of the tracking wheel principal. Unlike the tracking wheel, however, the specimen in this case was stationary. Tap water, with a resistivity of 1200 ohm·cm, was sprayed over the ECA unit while energized at various voltages. The water, with a precipitation rate of five inches per hour, was cycled on and off each minute, so as to have a drying period. This cycling is an important aspect of this test, as surface tracking is primarily due to the mechanism of discharges between water droplets. A flood of water on a sustained basis is not as severe as a fine mist or light shower. The effect of the tap water not only provided a higher value of leakage current than might be encountered in normal service, but it also allowed the buildup of minerals which simulated a condition of contamination which might be enountered in actual field service.

The leakage current across each specimen was monitored on a strip recorder. Typical results are shown in Fig. 10. Included for comparison are the results of a similar test of an all-porcelain assembly. These results have an immediate short-term effect in pointing out the comparative performance of various combinations of epoxy and ceramic materials.

Table III is a resume of the results of the wet cycling tests on several designs of ECA units. It should be noted that the suspension type unit is favored, due to its inherently low leakage current. This is, of course, due to the longer shielded leakage path provided by the suspension insulators. This same principle holds true for the crossarm assemblies.

It should be noted that, while the leakage currents for a post type unit are not as favorable as those of a suspension unit, additional study has brought forth a method of minimizing its effects. Early tests indicated that the bond line at the junction of the porcelain and epoxy in a post type unit was particularly susceptible to tracking, partly due to the shielding by the insulator. This was eliminated by providing a metal ferrule for the attachment of the insulator. This, in addition to allowing easy replacement of the porcelain unit in the event of chipping or breakage, also serves to distribute the leakage current evenly over the surface of the epoxy and glass member. This reduces the energy density gradient and increases the relative tracking resistance.

Field Tests: Complete ECA Units

All these tests are, by their very nature, only capable of providing a measure of relative performance. Laboratory tests notwithstanding, the only test which will provide conclusive information concerning the longevity of ECA units is time itself. Therefore, in addition to the short-term tracking tests, extensive tests have also been initiated on a long-term basis.

Figure 11 depicts one such ECA unit under test. This 6-foot arm with one 6-inch suspension insulator has been energized at 80 kV to ground for almost three years. While this particu'ar assembly is not a recommended installation, it has not displayed any indication of tracking, although it is continually energized and subjected to wind, rain, and dust. Another unit is seen in Fig. 12. Originally intended for 15-kV distribution service, this standoff bracket has been energized at 80 kV to ground since June 1965. A counting circuit monitors the number of discharges across this unit. These discharges occur quite frequently during rain showers; however, this unit has not displayed any evidence of tracking, although energized at approximately ten times its intended rating.

Although the design of the ECA units has been *optimized* to provide the maximum in electrical and mechanical properties with existing materials and technological developments, research continues. One of the most recent findings is a coating which extends the tracking resistant properties of the ECA units by 300 percent or more with one spray-applied coating. Multiple layers will add additional life. This coating, while resisting carbonization, does erode and chalk when subjected to high-energy discharges. It is thus sacrificial in nature. Restoration of the coating will provide additional years of service life.

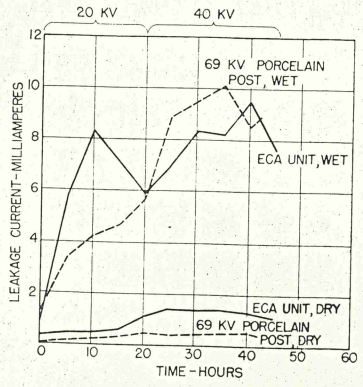


Fig. 10. Leakage current variation as a function of time during wet cycling tests for ECA of Fig. 4.

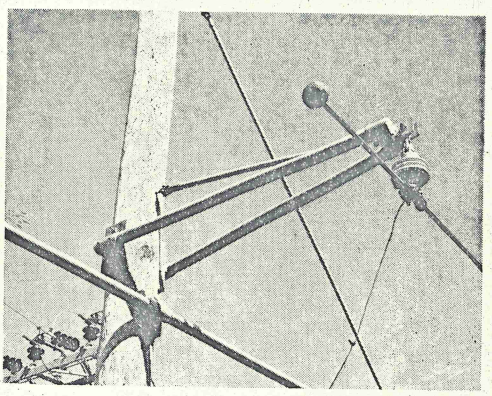


Fig. 11. Six-foot ECA crossarm with one 6-inch suspenion insulator undergoing sustained 60-Hz test at 80 kV. Unit has been energized since November 1963.

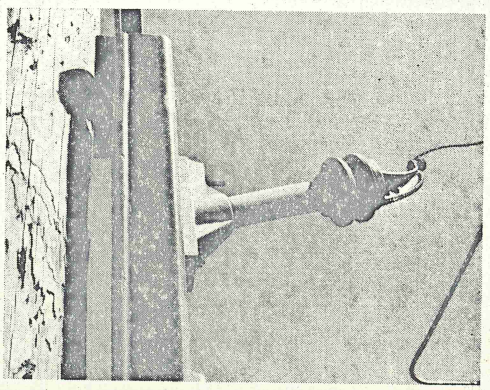


Fig. 12. ECA standoff designed for 15-kV distribution service, energized at 80 kV to ground since June 1965.

TABLE III

COMPARISON OF LEAKAGE CURRENT MAGNITUDES OF SEVERAL UNITS TESTED BY WET CYCLING METHOD

(*Applied voltage, 40 kV*)

Item Tested	Maximum Dry Period Leakage Over 24 Hours, mA	Maximum Wet Period Leakage Over 24 Hours, mA
ECA suspension unit, Fig. 2	0.6	1.6
ECA post type unit, Fig. 4	1.4	9.5
69-kV porcelain post	0.5	10.1

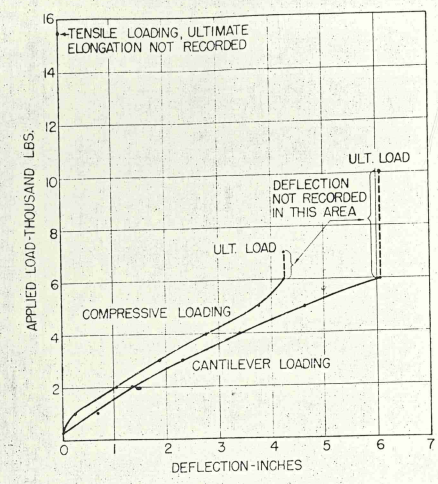


Fig. 13. Mechanical characteristics of 6-foot ECA crossarm.

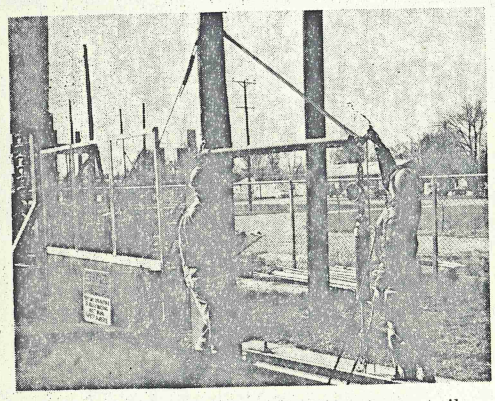


Fig. 14. Six-foot ECA crossarm undergoing cantilever test.

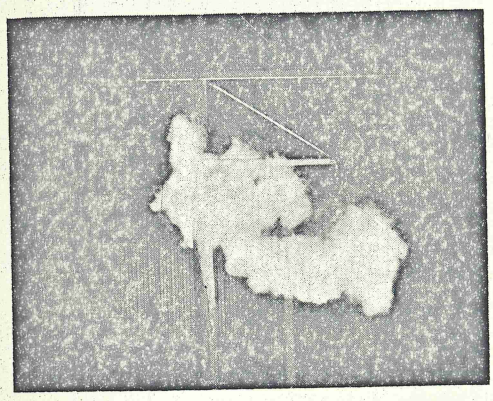


Fig. 15. Power follow test of 6-foot ECA crossarm at 23 000 amperes.

Weathering

Related to the tracking phenomenon is the deterioration of plastic materials due to environmental conditions. The effects of wind, rain, and snow are generally slower acting but will cause chalking and surface degradation similar to that caused by surface discharges. Although an ultraviolet inhibitor is contained within the epoxy system, UV radiation will cause degradation of the surface within two to five years. This degradation takes the form of chalking or, in the more advanced cases, will expose the outermost spiral wrap of glass fibers which are, on the average, only 0.001 inches below the surface. Short-term electrical characteristics exhibit no change due to this exposure of glass fibers. However, this does have a tendency to reduce the tracking resistance of the epoxy component. The addition of the external coating, in addition to prolonging the service life through its track resistant properties, also increases the service life by reducing the surface degradation due to ultraviolet radiation. Tests conducted under accelerated UV radiation conditions indicate an expected increase of service life of over ten years before restoration of coating is required.

Mechanical Properties

Mechanical tests conducted on naturally weathered samples of the epoxy and glass components over the past three years indicate a small loss in mechanical properties due to exposure of glass fibers near the surface. However, with the addition of the surface coating, it is logical to expect this factor to be of little concern, since dissipation of the coating will not affect the mechanical properties.

Typical mechanical characteristics of a 6-foot ECA crossarm assembly of the type shown in Fig. 1 are shown in Fig. 13. This arm is pictured undergoing test in Fig. 14.

Other researchers in the field have confirmed the excellent mechanical characteristics of epoxy systems and the advantages of the continuous filament method employed in the epoxy and glass system used in ECA assemblies.[6]

Power Follow Tests

Power follow tests at 60-Hz were also performed on an arm of this type. Figure 15 depicts one of a series of such tests at currents up to 23 000 amperes for a duration of 15 cycles. Both dielectric and mechanical tests of the arm indicated no change in any of the properties other than the physical appearance. This was characterized by a smoked appearance of the surface coating near the base casting.

Application of ECA

The ECA insulation system concept, together with favorable revisions in ground clearances set forth in the sixth edition of the NESC, have provided some interesting and practical opportunities for upgrading existing transmission lines to higher voltages and for improvement in new construction.

Figure 16 shows an application of the ECA of Fig. 2 at 69 kV on new construction. For urban areas, this type of installation provides a silhouette usually associated with lower voltage distribution lines, thus it may assist in overcoming objections to appearance.

Figure 17 shows a 3-step conversion utilizing an ECA to upgrade an existing 69-kV wishbone structure to 115-kV nonshielded construction.

Figure 18 is a test application of ECA at 110 kV on existing H-frame construction. The contrast in appearance is evident. Seven suspension insulators normally used with the wood arm were reduced to four to allow installation of the ECA which uses three insulators.

Figure 19 shows a planned structure conversion for upgrading an existing 115-kV line to 230 kV, utilizing ECAs to shorten the insulator string length and to restrain the center phase.

Figure 20 is a planned installation of ECAs for single-pole construction in a project to convert an existing 44-kV circuit to 161 kV.

Contamination

When considering the effects of contamination, it must be recognized that the atmosphere in all areas has different degrees and kinds of contamination at different times. Particles of contamination deposited on electrical insulation of any kind may themselves become conductive and cause leakage currents to rise. The effect of such action on the insulating member will vary with each condition of contamination and with the type of insulating members used.

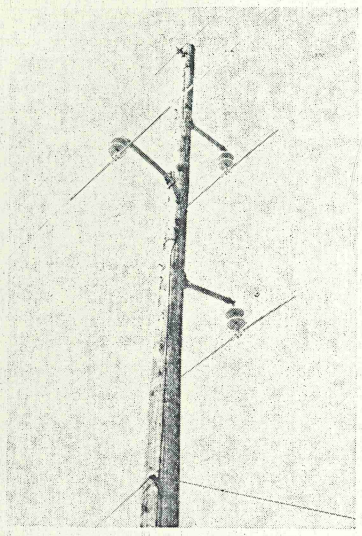


Fig. 16. Application of ECA suspension unit at 69 kV on new construction.

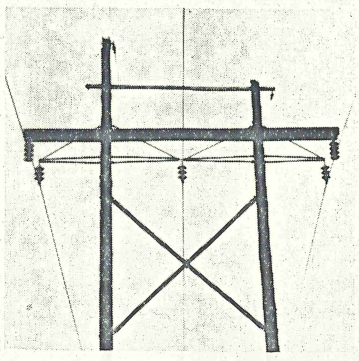


Fig. 18. Field test of ECA crossarms at 110 kV on existing H-frame construction.

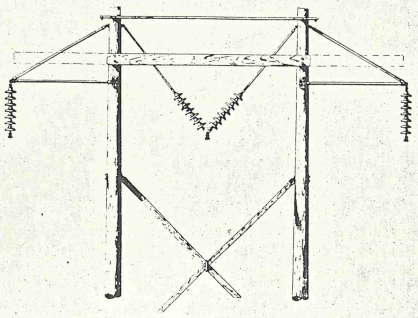
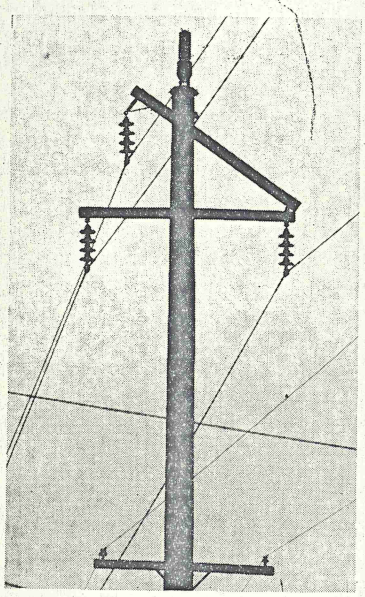
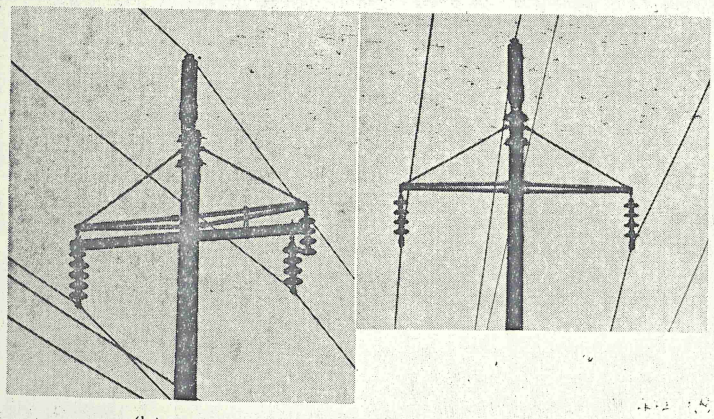


Fig. 19. Planned structure conversion for upgrading existing 115-kV line to 230 kV, utilizing ECA crossarms.



(a)



(b) (c)

Fig. 17. (a) Initial phase of conversion of 69-kV system to 115 kV. (b) Intermediate step in conversion. (c) Completed conversion to 115 kV using ECA crossarms.

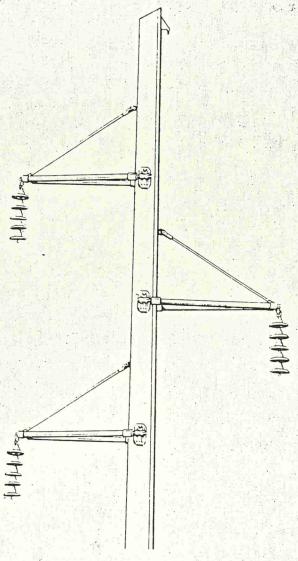


Fig. 20. Planned installation of ECA crossarms for single-pole construction in project to convert existing 44-kV circuit to 161 kV.

Areas having large atmospheric concentrations of coal dust, cement dust, fertilizer particles, sulphur, salt spray, and the like, where insulation problems are normally acute, may be called *severe contamination areas.*

ECAs with reduced amounts of ceramic are not recommended for such severe areas. However, ECAs with an amount of ceramic comparable to that presently accepted would be expected to lengthen considerably (but not eliminate) the interval between cleaning operations, this being due to the ECA presenting a lesser and smoother surface area to the collection of contamination than might otherwise be present.

Failures

In the early developmental stages of ECAs, the Chance Company entered a joint experimental project with a utility to design and try an ECA jumper restraining strut at voltages from 138 to 345 kV. The ceramic configuration and amount was minimized to that approaching the values for a 22-kV system. Several of these trial units failed by tracking due to excessive leakage currents, but several are still in service and much knowledge was obtained. The original experimental design has long since become obsolete.

A *successful* failure of a trial installation was recently reported. An ECA tangent bracket designed for a 15-kV spacer cable system was used in conjunction with one 6-inch distribution insulator on a 34.5-kV open wire system in an industrial area of severe contamination. The ECAs were coated with silicone grease. Tracking occurred after 15 to 16 months of duty, and replacement with similar units was then made.

Although such applications at 34.5 kV must be termed experimental, and the silicone greasing practice may be debatable, the ECAs apparently provided sufficient longevity to warrant their continued use, this in lieu of a much shorter cleaning and change-out cycle previously experienced with conventional construction.

Conclusion

New innovations in overhead system pole framing and insulation techniques are needed to solve present-day problems of appearance, reliability, and upgrading of lines. ECAs are developing to fill such needs.

Although the life expectancy of ECAs cannot be predicted with any more certainty than for other new innovations, this is not to imply that the life expectancy is short. Sufficient testing and favorable field experience have been accumulated to date to indicate continued use.

Testing of various ECAs and components indicates that plastics, including the epoxies, will eventually track when used by themselves in direct contact with energized conductors. However, when used in conjunction with ceramic materials in series and properly applied, the resultant ECA does not track.

The ECA insulation system and concept is predicted on the probabilities of achieving successful operation by combining different insulating materials in proportions related to maximum and minimum conditions, thus accounting for extremes and contingencies while providing the basic requirements in accord with established practice and materials.

In many situations, ECAs provide economic solutions to pole framing and clearance problems associated with conversion of existing lines to higher voltages.

References

[1] P. L. Bellaschi, "Insulation requirements of high-voltage transmission lines for 115 kV to 460/500 kV," *Trans. AIEE*, vol. 78, pt. III-A, pp. 231–239, June 1959.

[2] AIEE Committee Report, "Impulse flashovers of combinations of line insulators, air gaps, and wood structural members," *Trans. AIEE*, vol. 75, pt. III, pp. 16–21, April 1956.

[3] Dean, Wood, Russell, Doescher, Armstrong, Robertson, Bryant, Barthold, and Turner, "Insulation tests for the design and uprating of wood-pole transmission lines," *IEEE Trans. Power Apparatus and Systems*, vol. PAS-85, pp. 1258–1267, December 1966.

[4] E. L. C. Larson, M. Broschat, and R. L. Thompson, "Transmission line uprating 115-kV to 230-kV electrical and structural design," *IEEE Trans. Power Apparatus and Systems*, vol. PAS-86, pp. 539–546, May 1967.

[5] M. Kurtz, "The resistance of electrical insulating materials to surface tracking," *Ontario Hydro Res. News*, vol. 15, no. 3, pp. 29–33.

[6] J. W. Davis, J. A. McCarthy, and J. N. Schurb, "The fatigue resistance of reinforced plastics," *Materials in Design*, pp. 87–91, December 1964.

Discussion

M. Kurtz (Ontario Hydro, Toronto, Ont., Canada): This paper describes an approach to overhead line insulation that appears to hold great promise from the point of view of appearance and economy in pole or tower construction.

A major factor contributing to a viable ECA design is described in Merkhalev and Solomonik,[1] with reference to flashover of porcelain suspension units. It is well known that conductive moisture films on insulators will usually begin to dry out in regions of maximum current density, which are usually also regions of maximum field gradient, such as around the pin of a suspension unit, and arcing and scintillation will generally start in this area. Unless contamination conditions are very severe (or tracking has begun), these scintillations will cease as soon as a sufficiently long path to withstand the operating voltage has been dried.

It would appear, then, that a good ECA design (as those in the paper appear to be) would be such as to ensure that maximum leakage current densities always occur on a porcelain surface. If enough porcelain can dry off fairly rapidly to withstand the operating voltage, the epoxy portion of the assembly need never be exposed to conditions leading to tracking.

Manuscript received July 7, 1966.

[1] S. D. Merkhalev and E. A. Solomonik, "The mechanism of discharge development along the contaminated surface of insulators," *Elekt. Stantsii*, no. 12, pp. 50–53, 1964.

P. L. Bellaschi (Consulting Engineer, Portland, Ore.): For some time now, more and more of the utilities have been confronted with the problem of upgrading existing lines to higher voltages because of: the limited rights of way available in the first place; the pressure to reduce unit cost of transmission and subtransmission; the question of aesthetics; as well as other issues. In view of this situation, the developments described in the paper by Mr. Hally and Mr. Popeck are timely indeed.

Whether applied to transmission lines or to station equipment, insulation must be suitable for the conditions of service, which basically are three: lightning or impulse voltages, switching surges, and continuous 60-Hz voltage. The thoroughness with which the authors have pursued the development and application of ECA insulation with reference to these requirements is commendable.

We need not elaborate that most difficult of all to establish is the ability of the insulation to withstand 60-Hz continuously, for here we are dealing with the task of determining the life of the insulation. In this connection, the authors have been guided by the good basic approach which comprises: 1) fundamental tests and laboratory research directed to the epoxy material per se, 2) overvoltage tests on complete ECA insulation designs under exposed conditions closely approaching or as encountered actually in service—some of these long-time tests are now extending to three years, and 3) installations based on conservative designs, applied to transmission and subtransmission lines in various areas of the U.S.A. Equally important

Manuscript received July 25, 1966.

too, in the overall development and in the interest of gaining *life experience*, have been the few *experimental* installations in which the design intentionally was directed to burden the duty on the epoxy component, to accelerate the life.

The writer has just returned from an extensive trip to Europe, and finds that epoxy insulation is being applied increasingly to HV and EHV. For example, in the oil terminal of HV and EHV bushings, including 750-kV, in some designs the porcelain housing has been replaced entirely by an epoxy housing. Epoxy insulation components are now being applied in transformers and other equipment in all voltage classes. Over the past decade, the designer has found more and more that there is a limit to what he can do with porcelain, and in many applications epoxies have replaced the porcelain effectively and to economic advantage. The insulation system basically must be sound and suitable for the application and this is of paramount importance. In time to come, we can well anticipate, therefore, greater use and application of epoxies both in equipment and transmission lines, as is the case here.

E. G. Lambert (Pacific Gas and Electric Company, San Francsico, Calif.): The authors should be commended for taking a new look into the insulator problem of overhead lines, not only for the new material introduced, but also for its use in the overall insulator concept.

The life expectancy of ECA seems to be determined by the external coating of the epoxy component. During construction and maintenance of ECA systems, scratches, nicks, and abrasions are inevitable and would be very difficult to detect. The tracking properties of a material are certainly a function of the arc which develops due to the nonuniformity of the resistance of surface moisture. The surface imperfections would seem a likely place for tracking to begin. The importance of the external coating of the epoxy component makes it very desirable that the coating could easily be applied in the field, whether to correct surface imperfection or to extend the life of the assemblies due to weathering. What effects do surface imperfections have, and can these be easily corrected in the field?

Although the authors have lightly touched on the aspects of contamination, this problem is certainly a growing concern with increasing population. Our testing under severe contaminated conditions shows that a thin crust of contamination forms over the entire insulator and that the 60-Hz flashover strength is significantly reduced as compared to the clean wet flashover. Using the ECA systems shown in Figs. 1 and 4, and test results plotted in Figs. 5 and 8, the difference of 60-Hz wet flashover from the dry value is from 5 to 15 percent greater than that of the porcelain itself. This leads one to believe that as contamination becomes more of a problem, the ECA system will rely more and more on the porcelain component. The epoxy component in the horizontal position seems to provide a uniform wet film and become a more conducting member with increasing contamination.

Manuscript received August 1, 1966.

J. M. Bryant (Tampa Electric Company, Tampa, Fla.): The authors and their sponsoring company are to be commended for their bold step into the field of line insulation. It is certainly this kind of attitude which will cause this industry to continue to progress.

Tampa Electric Company is presently installing some two and one-half miles of 69-kV line utilizing ECAs. This will be our first venture into this concept, and we are hopeful that it will be successful. The insulation will consist of an epoxy–fiberglass arm $2^1/_2$ inches in diameter and 36 inches long, and three Chance 66-666 insulators in suspension.

There are some apprehensions about using ECA for these reasons:

1) Maintaining quality service on a long-term basis appears questionable. Using the all-porcelain insulating system, we expect the insulation to provide quality service for a period of 20 to 30 years. Now, we introduce an insulation system for which we have no *feel* as far as its endurance is concerned. The weathering of the plastic materials and the external coating give us a life expectancy in excess of ten years for ECA. It would appear that this is far too short a life to warrant its use.

2) Contamination effects may be too great. While ECAs are not recommended in severe contamination areas, there may be some difference of opinion as to where severe begins and stops. It then remains to be proved in the field whether or not ECA will actually do the kind of job to which our customers have become accustomed.

Why, then, have we decided to use some ECAs on our system? First, we believe that these assemblies offer a far better-looking line than conventional crossarm and insulator assemblies. Also, the cost of the ECA is competitive with the conventional construction on our system, and the availability of suspension insulators may be uncertain on today's market.

After we have had some operating experience with ECAs, we will either add to our apprehensions or strengthen our reasons for using them. We hope it will be the latter.

M. R. Boess, Jr. (Arizona Public Service Company, Phoenix, Ariz.): The authors present here a careful balance of pros and cons regarding the epoxy–ceramic assemblies. While they have presented the reasons, methods, and advantages of ECAs, they have discussed and defined their weaknesses without glossing over failures.

On this basis, engineers may examine the concept and consider whether the performance and cost are compatible with their particular problem. At Arizona Public Service Company, we used ECA in a 345-kV shoo-fly for several months when some reconstruction was necessary. The delivery and cost were attractive and the performance was highly satisfactory. Insulator strings of porcelain were attached to wood poles, and an ECA was used as a push-brace to hold the lower end of the porcelain string out from the pole surface a proper distance. Three such insulator assemblies were mounted on each pole, and side guys were used to hold the eccentric loading. These units are available for such future use, should the need arise.

As appearance becomes more of a factor in line design, such designs as the ECA will be used. Pole-mounted ECAs are being used for 12-kV lines in some applications.

There is no question that short-term performance of ECA is very good. That the surface of the plastic deteriorates and must be restored will be a problem for some applications. However, wood crossarms have predictably poorer electrical qualities than ECA and do deteriorate physically. When the maintenance involved with wood arms and their physical life is considered, ECA may be more attractive to prospective users. Based on performance to date, it is virtually a surety that the coatings which extend the life of these ECAs "by 300 percent or more" will be improved considerably in the future.

The authors' suggested design application, wherein porcelain insulation is provided for a twice line to neutral voltage switching surge and the epoxy assembly providing for an additional margin up to four times line to neutral, makes very good sense. Many companies (including Arizona Public Service Company) can point with pride to excellent system operating records over lines designed for switching surges of 2.5 times line to neutral. In areas where contamination is a major factor in determining insulation, the engineers directly concerned with the problem are in the best position to evaluate whether ECA is suited to their needs.

There has been wide experience in the industry with fiberglass and epoxy guy strain insulators. Their good performance helps answer questions about the mechanical performance of these materials.

The present tremendous expansion of facilities by the utility industry is placing very heavy demands on the insulator suppliers. Such imaginative answers and continuing development programs will help provide for the necessary new plant.

Manuscript received August 1, 1966.

C. B. Benham (Florida Power Corporation, St. Petersburg, Fla.): The authors' paper covers a system previously reported by Lancaster[1] for use on a 230-kV tower; however, the authors' present test data provide sufficient background for numerous applications. They note that the concern for the tracking phenomenon associated with organic materials has diminished as application limits have been developed and field experience has increased. A previous article[2] noted that "success will depend principally on the ability of the rods to withstand leakage currents without tracking. If a sufficient number of insulators is used in series with the rod, there is little doubt that successful operation can be obtained in areas of mild contamination. If, however, an inadequate number is used, then one may expect tracking. Once tracking starts, it will increase progressively until failure occurs."

The discusser feels that this ECA insulation system is a real breakthrough for lines which are lightning limited, but not for lines which are limited by switching surges.

On May 24, 1966, a 5-unit string of insulators on a 69-kV wood pole flashed over and failed when sectionalizing switches were reclosed. This 5-unit string was in series with 4 feet 8 inches of wood, but the arc destroyed the petticoats on the bottom insulator and the second one from the top, and burned through the steel cap of each of the top three units, the largest holes being 5/8 inch in diameter. The arc also burned off the head of the through-bolt on the bayonet. The insulators which flashed over were brand new and had just been installed a few hours previously. They were standard $5^3/_4$-inch by 10-inch B&S insulators manufactured by a company with a long established reputation. Although the heat of the arc was great enough to result in electrical failure of the porcelain, the string did not fail structurally, i.e., the conductor was not dropped. Would the authors feel that an ECA system of the same leakage distance would be reasonable?

Providing adequate leakage distance is used with the ECA system, the discusser feels considerable economies and satisfaction with applications will result.

Manuscript received August 1, 1966.

[1] E. L. Lancaster, "Use of epoxiglas in series with porcelain," Southeastern Electric Exchange Rept., October 1964.

[2] E. L. Lancaster, "Epoxiglas supplements porcelain," *Elec. World*, pp. 60–61, August 9, 1965.

H. G. Hally and **C. A. Popeck:** The authors wish to thank the many discussers for their frank comments relative to the paper. We felt that Mr. Bryant's statement referring to the activities related in the paper as a *bold step* was very appropriate. While perhaps it is a bold step in the sense of being a departure from what is accepted practice in relation to present-day line insulation techniques, it is by no means a departure from sound engineering judgment and investigation. On the contrary, we believe that the ECA program has produced results which, if at all bold, are well on the conservative side. We obviously cannot predict with any certainty the expected life of ECA units beyond a reasonable range of laboratory and field data. However, this is not to imply that the life of ECA is short. Each day gives us increased knowledge of the longevity of ECA units and increases our confidence in them. Our statement regarding an expected service life in excess of ten years for ECA units should not be interpreted as indicative of the life expectancy. Only with time will we be able to predict accurately the life of ECA units, by use of the very unscientific method called hindsight.

In addition to the many ECA units in actual service, other installations have been made on a test basis under extremes of environmental conditions. The results of such programs will enable us to establish parameters for rating ECA units under conditions of severe contamination. As Mr. Boess so well points out, the search for improved coatings and materials is continuing with the promise of extended life under extreme service conditions.

The question of the effect of surface scratches has been considered. It must be remembered that the surface of the base material is itself highly track resistant. Therefore, exposing it at random in small areas would not appreciably decrease the life expectancy of the unit. Exposure of large areas of the subsurface could reduce the life expectancy, but the degree of reduction is dependent upon the area exposed and service conditions. No attempt has been made to correlate life expectancy with the degree of subsurface exposure. It is recommended that surface imperfections large enough to be readily apparent at the time of installation be restored by a field application of the exterior coating material to the damaged area. This can be done without difficulty.

In regard to Mr. Benham's comments on lightning and switching surge limitations, we wish to point out that the ECA concept does not represent a system of reduced insulation. Rather, it is one employing the use of two insulating components of which one, i.e., porcelain, may be of a lesser amount than conventionally used.

Since the presentation of the paper, additional test data have been obtained concerning the switching surge properties of the ECA crossarm unit of Fig. 1. The results are given in Table IV.

TABLE IV

SWITCHING SURGE WITHSTAND AND FLASHOVER VALUES USING A WAVESHAPE OF 116- BY 4350-μS

Test	Withstand Crest, kV Uncorrected	Withstand Crest, kV Corrected	Critical Crest, kV Uncorrected	Critical Crest, kV Corrected
Positive polarity dry	865	893	934	964
Negative polarity dry	1080	1118	1104	1152
Positive polarity wet	750	767	925	945
Negative polarity wet	783	818	905	945

The authors wish to congratulate the discussers for their foresight in recognizing the need to evaluate promising new techniques and methods, which are beyond the laboratory stage, by the only positive method presently known, that of actual service installation.

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MECHANICAL RATINGS OF NON-CERAMIC INSULATORS

DISCUSSION PAPER

FOR

WG on Non-Ceramic and Composite Insulators for Transmission Lines

Discussion Prepared

by

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I. Introduction

Traditionally, one selects transmission line insulators by computing expected loading and multiplying it times a safety factor to obtain a required M&E strength. Typical loading and safety factors used to establish M&E ratings on a 550 kV deadend assembly are shown in Table 1.

The three factors; expected loading, safety factors, and M&E ratings have been developed over many years of experience and testing with porcelain insulators. To apply these factors to non-ceramic insulators would be meaningless; thus, new criteria must be developed.

The development of this new criteria requires first, a detailed knowledge of material properties and failure characteristics for the non-ceramic insulator, and second, a detailed knowledge of all loading, environmental factors, and electrical parameters found to affect failure characteristics or material properties.

II. Failure Characteristics of Non-Ceramic Insulators

The three most common parameters used in the specification of ceramic insulators are average breaking strength, standard deviation of breaking strengths, and proof test load. The proof test load might be considered to be the minimum insulator mechanical strength since ideally all insulators with breaking strength below this level are eliminated prior to shipment. The insulator rating might then be defined as the average breaking strength less three standard deviations.

There is an implied assumption when using these parameters. One assumes that so long as the actual load has never exceeded the proof test load, and the insulator has not been broken by some other means, the mechanical strength of the insulator is independent of its history. For example, loading a 40,000 lb M&E insulator with 20,000 lb for 30 years should not decrease its mechanical strength. In reality this assumption is false even for porcelain insulators; however, it is not normally a major consideration.

Non-Ceramic insulators using fiberglass-polymer rods for their strength element have a time-load characteristic that differs appreciably from conventional ceramic insulators. A hypothetical example is shown in Figure 1. This load time curve creates the fundamental question: does the historical loading of the insulator change the short time or long time mechanical strength characteristic? If so, then one must specify mechanical properties (e.g. mean and standard deviation breaking strength) both in terms of load duration and historical loading conditions.

Although the curves of Figure 1 are purely hypothetical and have no real basis (no data is available), they illustrate the dilemma faced in determining mechanical requirements for an unproven product. Any real specifications must be based on knowledge of the following:

1. What constitutes a "normal" failure and what constitutes a "maverick" failure? A test must then be devised to eliminate the mavericks before they leave the factory.

2. What is the statistical distribution of "normal" failures for types of loading expected in field use? The load-time curve published by Rosenthal and others is an example for constant load. Other examples should include step and cyclic loading.

3. What effect does preloading have on the distributions found in item 2? For example, if one were to load the insulator at its "rated working load" with occasional short time loads to twice its "rated working load", will the mechanical strength of the insulator be permanently decreased below that expected from the "no-preload" load time curve?

4. What effect does the environment (sun, temperature, contamination, etc.) have on items 2 and 3?

5. How do electrical discharges, etc. affect items 2 and 3?

The amount of testing and studies necessary to develop a specification tends to boggle the mind and drive both manufacturer and utility users up the wall. One is often tempted to simplify the procedure by specifying a very large safety factor and assuming that minimum strength will rarely, if ever, degrade sufficiently to cause failure. This is not the purpose of this WG; thus, we feel it is premature to specify either the final test methods or required safety factors.

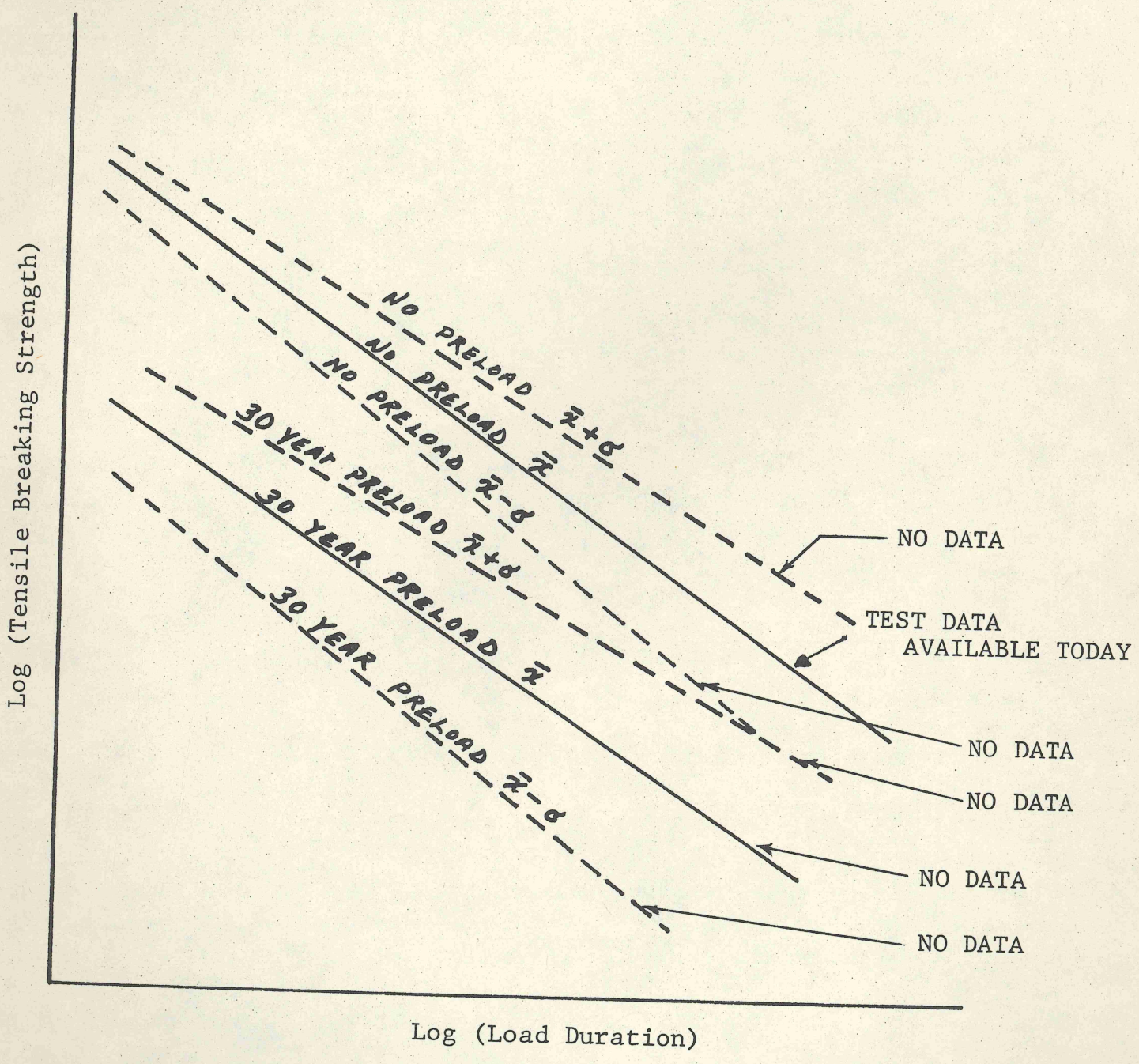

Figure 1. Hypothetical Load Duration - Strength Curves for Non-Ceramic Insulator

TABLE I: Insulator Loading and M&E Ratings for Porcelain Deadend Strings - 550 kV, Two Conductor 2156 kCM ACSR Bundle, 1800 Foot Ruling Span, California Light Loading

Type of Loading	Temperature (F)	Wind Load (lbs/ft^2)	Ice (Inches)	Loading (lb)	Safety Factor	Minimum Required M&E Total (lbs)	M&E per String of 4 String Bundle
Calif. Light Initial Sag	25	8	0	41502	3	124,506	40,000 lb
Everyday Final Sag	60	0	0	25272	4.5	114,873	30,000 lb
Residual-one string out, remaining at 2/3 strength final	25	8	0	41502	1.5	124,506	40,000 lb

III. Insulator Loading

The mechanical load seen by the insulator is a function of the original transmission line span length and sag, the temperature, wind loading, and ice loading. For deadend strings, the tensile load on the insulator assembly is equivalent to the conductor tensile load.

Strength requirements for both insulators and conductor are based on meteorological conditions found in the area traversed by the transmission line or as defined by regulatory codes. For example, the California Public Utilities Commission defines a light loading area as one in which the most severe expected condition is 25°F with 8 lb/ft^2 of wind. A heavy loading area has an expected severe condition of 0°F, 6 lb/ft of wind and 0.5 inch of ice. The term "design loading" is that loading condition determined by the regulatory codes or meteorological investigations, whichever is the more severe.

A. Deadend Insulator Assemblies - Tensile load on deadend insulator assemblies is equal to the conductor tension. Southern California Edison practices for conductor tension are as follows.

1. Maximum Working Tension: The maximum working tension of the conductor under the heaviest resultant design loading shall not exceed 35 percent of the ultimate conductor tensile strength. This may be taken as the worst case or once in 50 year storm. For example, the ultimate strength of ACSR 2156 kcmil Bluebird is 60,300 lbs. The maximum working tension of a two conductor bundle would be 2 x 60,300 x .35 or 42,210 lbs.

2. Initial Unloaded Tension, Stringing: The initial unloaded tension, without wind or ice, of the conductor at the minimum expected temperature during sagging operations shall not exceed 30 percent of the ultimate conductor tensile strength. Maximum initial unloaded tension for the above 2 conductor Bluebird bundle would be 2 x 60,300 x .30 or 36,180 lbs.

3. Final *Unloaded Tension, Cold: The final unloaded tension, without wind or ice and after effective creep of the conductor at such minimum temperatures as established for the design loading, shall not exceed 25 percent of the ultimate conductor tensile strength. Final unloaded tension for the two conductor Bluebird bundle will be less than 2 x 60,300 x .25 or 30,150 lbs.

4. Final *Unloaded Tension - Everyday Loading: The final everyday tension, without wind or ice and after effective creep of the conductor at 60° F shall not exceed 22 percent of the ultimate conductor tensile strength. Everyday loading of the two conductor Bluebird bundle will be less than 2 x 60,300 x .22 or 26,532 lbs.

Examples of deadend assembly tension are shown in Table II.

*Final sag is reached in approximately 10 years, with the majority of creep occuring during the first year.

Table II: Deadend Insulator Assembly Tension for Typical 550 kv Two Conductor ACSR Bluebird 1800 Foot Span Designed for California Light Loading (25°F, 8 lb wind, No ice).

Temperature (°F)	Wind (lbs/ft^2)	Ice (Inches)	Initial Tension (lbs)	Initial Tension % of Cond.	Final Tension (lbs)	Final Tension % of Cond.	Note
0	0	0	40304	33.4	26808(3)	22.23	Conditions
0	0	0.5	54854	45.5	40316	33.43	more severe
0	0	1.0	71974	59.7	58436	48.45	than design
0	0	2.0	105312	87.3	105312	87.3	load
0	6.0	0.5	57036	47.3	42486	35.2	Calif. Heavy
25	0	0	38592	32.0	25852	21.4	Conditions
25	2	0	38774	32.2	26014	21.6	less severe
25	4	0	39306	32.6	26490	22.0	than design
25	6	0	40164	33.3	27262	22.6	load
25	8	0	41304(1)	34.3	28298	23.5	Calif. Light
25	12	0	44248	36.7	31020	25.7	Conditions
25	14	0	45960	38.1	32636	27.1	more severe
25	16	0	47782	39.6	34382	28.5	than design load.
40	0	0	37632	31.2	25756	21.4	Conditions
60	0	0	36430(2)	30.2	25272(4)	21.0	less severe
90	0	0	34774	28.8	24596	20.4	than design
130	0	0	32816	27.2	23772	19.7	load.

(1) Maximum working tension

(2) Initial unloaded tension

(3) Final unloaded tension-cold

(4) Everyday tension

B. Suspension Insulator Assemblies - Loading of suspension insulator assemblies consists of a vertical component (conductor, ice and insulator weight) and a transverse component (wind and angle). These loads are computed as follows:

1. Vertical Loads -

Conductor weight is the effective span length x number of conductors in bundle x weight of conductor per foot. For an 1800 foot span of two conductor Bluebird bundle, conductor weight is 2 x 1800 x 2.51 lb/ft or 9036 lbs.

Ice weight is the total ice supported by the insulators. For the above line with 0.5 inches of ice, F_{ice} is 1800 ft x 2 x 1.41 lb/ft or 5094 lb.

Weight of insulators will be negligible for non-ceramic.

2. Transverse Load

Wind load is the wind force (lbs/ft) times the cross sectional area of conductors. For the above 2 conductor, 1800 foot span, F_w = 2 x 1.762/12 x 1800 ft x 8, or 4229 lbs for a 8 lb/ft^2 wind. The wind force is approximately 0.0025 x V^2 where V is the windspeed in mph.

Conductor Tension is included into the transverse load if the transmission line is forced to make a bend at the suspension tower. Maximum angle using the Southern California Edison heavy tangent tower is 6°. Tension load on the suspension insulator assembly is T_c x 2 x sin (angle) where T_c is the conductor tension. Assuming maximum conductor tension (35% of ultimate) and a 6° angle, the transverse force is 4412 lbs for our example 550 kV line.

3. Resultant Load

For vertical strings, tensile loading is the resultant of transverse and vertical load. Typical values are given in Table III.

For V-Strings, tensile must be divided (vectorally) between the strings.

C. Abnormal Loads - Abnormal loads are those loading conditions which result from a failure of one or more components of the line or from an unexpected event. Examples, include:

1. Conductor Breaking - sudden load release on one insulator and load increase on remaining strings.

2. Insulator Failure - Remaining insulator strings must take sudden load increase.

3. Low Flying Aircraft - Very destructive to insulators, conductors and towers, aircraft, and aircraft occupants.

4. Galloping - Although listed as abnormal, conductor galloping is fairly common. It results in dynamic loading of the insulators.

Table III: Suspension Insulator Assembly Tension for Typical 550 kv Two Conductor ACSR Bluebird 1800 Foot Span Designed For California Light Loading.

Insulator Configuration	Angle of Line	Temp. (^{o}F)	Wind (lbs/Ft^2)	Ice Inches	F_V Vertical (lbs)	F_T (Trans) (lbs)	F_1 String 1 (lbs)	F_2 String 2 (lbs)
Vertical	0	60	0	0	9040	0	9041(4)	-
Vertical	0	25	8	0	9040	4228	9980	-
Vertical	6°	25	8	0	9040	12863	15722	-
Vertical	0	25	0	.5	14130	-	14130	-
Vee(90°)	0	60	0	0	9040	0	6392(4)	6392
Vee(90°)	0	25	8	0	9040	4228	9383	3403
Vee(90°)	6°	25	8	0	9040	12863	15490	0
Vee(90°)	0	25	0	.5	14130	-	9993	9993

(4) Everyday Load

IV. Other Mechanical Requirements

A. Thermal Strength

The fiberglass-resin rod matrix mechanical strength is a function of temperature. Tests to confirm the "RATING" should be performed at an ambient temperature of at least 70°C. (158°F)

B. Impact Strength

There should, at the minimum, be two (2) categories of impact strength:

1. Handling Abuse, which includes:

   a. Dropping

   b. Dragging

   c. Climbing

   Some non-ceramic insulators have soft sheds, others are very stiff. Can normal utility installation practice easily rip, tear, chip, or crack these units; and if sheds are demaged, does the entire, one-piece insulator have to be discarded? We have to insure that such insulators withstand the rigors of handling and maintenance.

2. Vandalism Abuse

   a. Residual Strength

   b. Hidden Damage

   What is the rod strength after a non-ceramic insulator has been gun-shot; and can the damaged units be detected by normal line patrol? Suppose e.g., that a 243mm slug is captured by the rod; (1) How can this condition be detected; (2) What happens to the tensile strength in time; (3) Does RIV increase; (4) What happens if moisture invades an exposed rod interface?

C. Sudden Load Release

After a period of load application suppose the conductor fails for some reason and load is suddenly released:

1. Will the shed structure and/or rod survive the shock? And if there is damage, how is this damage detected?

2. Can the rod be loaded again to the same working load and the original tensile time-load curve still apply?

D. Vibration Effects

The effects on the mechanical properties due to whipping of a long rod from conductor galloping or aeolian vibration have to be understood and accounted for.

E. Flashover Effects

The mechanical degradation effects on the insulator due to a 60 Hz flashover must be considered.

How much strength degradation is there due to the heat generated from sustained arcing on the metal end fittings? Will the shed material burn and/or melt and allow the rod to become exposed to atmospheric conditions? Will the shed mechanical strength degenerate due to heat of the arc?

F. Crating Effects

We have seen some non-ceramic insulators which supported their own weight on their sheds, and the sheds took a permanent set. Therefore, non-ceramic insulators may have to be created and supported such that rod or sheds are not bent over a long period of storage time. Furthermore, if a bent insulator (rod) is loaded in tension will it fail?

V. Summary

This discussion paper has reviewed the common loading conditions and given illustrations of everyday loading, maximum loading, etc. The methods required to compute loading on insulator assemblies are well known.

Application of non-ceramic insulators for these loading conditions requires that a method to "rate" the insulators be established. It is our belief that insufficient information is presently available to define such a rating system. However, this paper outlines some of the parameters which are necessary to establish a system to load rate polymeric insulators.

CHARACTERISTICS OF FIBERGLASS AND POLYMER INSULATION

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INTRODUCTION

Although today we tend to think that porcelain line insulation has always given satisfactory operation, there really are several things historically not quite right with that point of view. For the first thirty years or so of its use, porcelain insulation was unreliable all too frequently. Fortunately, utilities and manufacturers alike learned the problems of porcelain, and designed the product and use of it to accommodate these shortcomings. Nowhere has that been truer than in suspension insulators. From the manufacturer's viewpoint, the product is slow to manufacture, heavy, and can be fragile if handled roughly. Designs and processes must reflect the inherent nature of the materials used. The utility is concerned with its bulkiness and weight, and must allow considerable warehouse space for its storage. The suspension insulator's arch enemy has historically been the gun carrying vandal, but more recently the ecologist has turned our attention to the appearance of its bulky profile, and the clutter on the pole top that can easily be caused with several porcelain discs in series.

Seventeen years ago we began to study outdoor high voltage insulation, asking whether some alternative might be found in the newer insulation materials. What developed from more than a decade of research and development has come to be known as the GEPOL® insulator. (Figure 1)

The GEPOL insulator is, properly speaking, a track-resistant, fiberglass reinforced polymer insulator. It depends for its electrical and mechanical integrity on a fiberglass reinforced central rod, about which is cast the track-resistant material, a flexibilized epoxy formulation.

It would have been possible to make a plastic insulator along these general lines twenty years ago. It would not have worked, however. Scientists and design engineers have known for many years that almost all organic materials will track when exposed to contamination and moisture outdoors in electrical service. Tracking may be defined as the formation of carbonaceous conducting paths on the surface of

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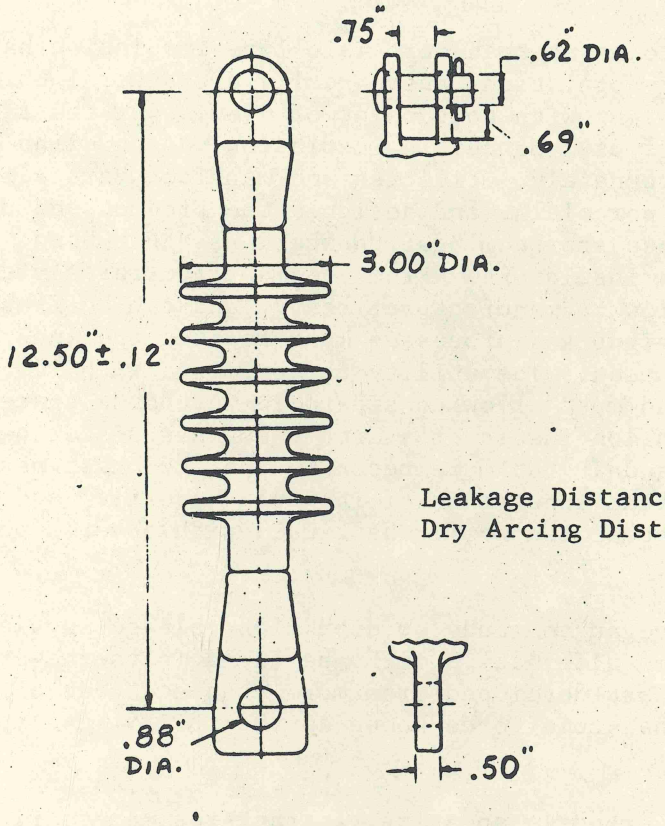

Leakage Distance, In.	14
Dry Arcing Distance, In.	7-3/4

Figure 1 -- 15 KV GEPOL Insulator Dimensions

insulators, and is caused by high leakage currents on wet, contaminated insulators. It was not until 1954, when General Electric scientists discovered the track-resistant properties conferred by hydrated alumina filler upon many polymeric systems, that the way became open for ultimate success. The basic novelty and benefit of this discovery was recognized in a series of patents granted by the United States and numerous foreign countries. The action of hydrated alumina appears to be due to the water released from the hydrate at the high temperatures ($>200^{o}C$) leading to carbonization. The water reacts at these temperatures with the carbonaceous materials, forming carbon monoxide and hydrogen. These two gases are volatilized and no track remains.

More work was required, however, to develop this basic idea to a level of commercial acceptance. Three general areas were found to be critical in this project, and each has received some years of attention. This paper will discuss briefly some of the many facets of this extensive development program. It was as a result of this laboratory work, many field trials, and finally widespread use, that today's GEPOL insulator has been proven successful for distribution voltages and installation practices.

ALTERNATIVES TO PORCELAIN SUSPENSIONS

Before we discuss the various necessary aspects of the distribution polymeric insulator, we might pause to consider what possible alternatives there were to porcelain in the 1950s. Fifteen years ago fiberglass reinforced structures were becoming well-known. We theorized that it should be possible to use one fiberglass rod of sufficient length for the entire insulator string, with only two rather small pieces of hardware, one on each end. This reduction in hardware joints should lead to improved RIV performance, because of greater electrode separation. Laboratory investigation quickly proved that although such rods are satisfactory for guy strain application, they are not track-resistant and are therefore completely unsatisfactory as primary insulation.

The next logical step was to give the fiberglass rod a track-resistant surface. Since we are porcelain manufacturers, our thoughts were to use porcelain discs with through holes in the center, so the discs could be stacked up along the length of the rod. A moment's reflection, however, indicates that though this does reduce the amount of expensive metal, it does nothing toward eliminating the weight and fragility of the porcelain. In fact, since the modular suspension unit is replaced by a much longer single insulator, the weight and general bulkiness is worse than in the standard unit, insofar as easy handling goes. It was at this point that it was decided to go the whole way to develop an entirely polymeric suspension insulator.

LABORATORY DEVELOPMENT WORK

As mentioned earlier, three fields of development were needed: materials for the insulation, hardware connection, and general shape of the sheds and insulator. Porcelain insulator technology was of rather little help, except that numerous test methods were ingrained in the industry; and any new product would be expected to conform to the standards used for porcelain, in test methods, quality and reliability.

The fiberglass rod is the basic element of the materials used in the polymer suspension insulator. It must be consistently electrically sound, and of a size sufficient to give the desired mechanical strength. This seemed a simple matter, but finding rod sources who could supply quality of the levels we set, and do so for the miles of rod needed, was not so simple. Some years of joint development of rods with several manufacturers were needed to overcome the problems of composition and satisfactory processing required to give high levels of quality and reliability. Today both epoxy and polyester rods of outstanding quality are possible, and either of these two basic resins can be used, if formulated, processed and cured properly.

The hydrated alumina filler used to achieve track resistance has already been mentioned. It was the single most important step required in the development program for the outer portion of the insulator, but was not the only one. The earliest epoxy resins, chemically known as the bisphenol-A epoxy resins, were greatly improved by the use of hydrated alumina. In the early 1960s, however, the newer cycloaliphatic epoxy resins were commercialized and proved to have inherently better electrical, outdoor, and track-resistant properties than do the bisphenol-A versions. Using the hydrated alumina and cycloaliphatic epoxy resins together gave outstanding track resistance in accelerated laboratory tests. In field use, we have never had a known case of tracking with this combination, with many tens of thousands in service.

One further requirement must be made of the outer material of the insulator: it must be somewhat flexible to withstand temperature cycling and overcome potential problems of brittleness and fragility. In addition, since it is bonded directly to the fiberglass rod, the outer material must be able to match the rod's expansion arising from the mechanical loads and temperature changes. Unmodified cycloaliphatic epoxy resins cured with conventional agents are generally glassy, brittle products, usually even more so than the related bisphenol-A epoxy systems. This brittleness may be overcome by use of a flexibilizer, but it is necessary to choose carefully so that no other property is compromised by this addition.

The earliest hardware attachment method used socket type hardware over the protruding ends of the fiberglass rod. A dozen years of field experience on utility lines has demonstrated the correctness of this approach. At one point we tried to use hardware which was connected inside the insulator to a fiberglass rod with loops on its ends. Although this led to high strengths, it unfortunately gave considerable difficulty in manufacturing insulators that were void free in high electrical stress areas.

The third major development area, shape of the insulator, particularly the sheds, is one that is still continuing for vertical transmission use. However, for distribution, which is entirely an horizontal application, a simple sinusoidal shape for the sheds has proven excellent in lab and field experience. Such a design allows maximum cleaning by rain, and sufficient leakage distance for all degress of contamination. Because the polymer unit is so lightweight, the insulator can be made in one piece, rather than modular. It is easily handled by the lineman, and requires no joining together of the sort done with porcelain discs.

FIELD EXPERIENCE

Our field experience is now twelve years old, and has been gained at voltages to 230 KV and beyond. Four basic units have been subjected to field trial: one designed for 115 KV, one for 69 KV, one for 34.5 KV, and one for 15 KV. Of these only the 15 KV unit has been commercialized, but higher voltage distribution units are planned for commercial release later.

The 69 KV unit was the first of all the field trials, and was surprisingly successful. Most of the units are still in service today, after twelve years. Those that have failed were all in the vertical position: we now know this was partly a matter of the early materials used, and partly a matter of shape.

The 115 KV field trial was the largest, best publicized in reports to the industry, and least successful. Not only did it suffer from use of the early resin systems, but also from poorer hardware connection methods and shed design than the earlier 69 KV unit had. If nothing else, it proved that it was very difficult to rely at that time on laboratory tests alone for evaluation, for these changes looked good when tested in the laboratory.

The 15 KV insulator design and application features greatly benefited from the earlier trials at higher voltages, particularly as we had come to recognize the significant difference between results obtained in the horizontal position as contrasted to the vertical. The 34.5 KV suspension unit has been in field trial now from two to three years at numerous locations around the country, without problems in the widely varying application conditions selected. Results should be

similar to those of the 15 KV insulator, for all distribution voltage applications are horizontal for suspension insulators.

POLYMER INSULATOR CHARACTERISTICS

So much for the history of the development and the proper components of a useful suspension insulator. What really counts for utility use is the features that can be obtained in a polymer-fiberglass insulator. Perhaps it is easiest to group the advantages into three major areas: mechanical, electrical, and other.

The polymer insulator offers mechanical strength ratings equal to the conventional proof test and M&E values of porcelain. In general the range of ultimate strengths obtained in a test sample is less for GEPOL than for porcelain, due to the less variable nature of the fiberglass rod compared to porcelain. Torsional strength, though not a rated value in suspension insulators, is a potential problem in any clevis type structure. The GEPOL insulator has a torsional strength equal to that typically obtained with 4-1/4" or 6" porcelain suspensions. Impact strength for the polymer unit is far greater than porcelain's--really not even comparable. Brittleness, fragility and thermal shock problems simply do not exist in the GEPOL insulator, whereas they are quite serious with porcelain when it is roughly handled, dropped, or shot at by vandals.

Many of the electrical ratings of the GEPOL insulator are quite similar to those required of two 4-1/4" or 6" porcelains. (Table 1). Wet flashover, however, is markedly superior in the polymer case. Puncture strength is very high: typical ultimate puncture values are around 240 KV, and of course can only be obtained under oil since they are far above the flashover strength. Even in oil, the unit usually flashes over rather than puncturing. This outstanding puncture strength is directly related to the long puncture path relative to the flashover path, as opposed to a quite short puncture path in porcelain suspensions. Although rated the same as porcelain, the radio and TV noise characteristic is another markedly better property in a polymer-fiberglass unit, and is related to the much greater separation of the electrodes in the insulator.

Among the other properties, weight and volume are reduced over 70% for the polymer insulator. These features are important in shipping, in warehousing, and in installation. Another installation advantage is in the single unit nature of the polymer insulator, which eliminates problems of handling two units joined together, with their tendency to flop one way or the other while being handled. Also important to the lineman is the small diameter, which is more readily covered while working it hot on the line.

Table 1

ELECTRICAL COMPARISONS

RATED PROPERTY	REQUIRED FOR 15 KV SYSTEM	15 KV GEPOL
60 Hz Flashover		
Dry (KV)	80	100
Wet (KV)	45	75
Impulse Flashover		
Positive (KV)	130	150
Negative (KV)	155	175
R.I.V., Max. (μv) @ 10 KV, 1000k Hz	100	50
Puncture, Min. (KV)	115	150
Arcing Distance (In.)	6-1/4	7-3/4
Leakage Distance (In.)	12	14

Table 2

OTHER APPLICATIONS

AIR-BLAST BREAKERS

-- 500 KV CT COLUMNS
-- 230 KV CT COLUMNS AND HORIZONTAL BUSHINGS

BUSHINGS

-- TRANSFORMERS
-- NETWORK PROTECTORS

VACUUM INTERRUPTER HOUSINGS

OPERATING CONTROL RODS -- SWITCHGEAR

PIN INSULATORS

RADIO TOWER INSULATORS

15 KV GEPOL IN-LINE SWITCH INSULATORS

Certainly among the other advantages should be listed the much slimmer silhouette and the resulting less cluttered appearance on the pole. This same slimness also makes the insulator a far more difficult target for the vandal, which coupled with the lack of fragility, makes the polymer unit virtually indestructible.

APPLICATIONS

The use of fiberglass-polymer insulators for distribution service has been evaluated by over 400 utilities, and accepted for use in significant volume by many. We anticipate that the number of those utilities specifying the polymer unit for use in their systems will continue to grow. Our plans and programs for further development are, of course, contingent upon wide acceptance by the utilities.

The General Electric Company is continuing its programs to expand the use of polymer insulators into higher voltage suspension applications. As mentioned above, higher voltage distribution suspensions will be commercially available later. Transmission studies are underway in our laboratories and outdoor sites, as well as at several cooperating utilities. Initial experiments, largely concerned with shed design, are very encouraging, but we will not commercialize any transmission product until sufficient field trials of several years' duration have demonstrated success under all conditions of use.

The 500 KV air-blast breaker housings manufactured in 1965 have been mentioned frequently in various speeches and papers since then. These experimental fifteen foot high housings continue to be the world's largest one-piece insulators ever made of any kind of material. More recently, we have made field trials of 230 KV breakers in which additional porcelain components were replaced by fiberglass-epoxy insulators. Both the 500 KV and 230 KV polymer insulator breakers are in active use at several utilities today.

We have also built experimental 115 KV bushings in which the usual porcelain housing has been replaced by a fiberglass tube covered with GEPOL. More work is planned with these and other high voltage bushing designs.

We have sold a number of other polymer insulator products for outdoor use in recent years. (Table 2). Though some are still in low volume, others have been sold by the hundreds or thousands. Our field experience from all the applications of the last five years has been uniformly excellent.

CONCLUSIONS

On the basis of all our laboratory and field experience with a wide variety of polymer insulator products, we believe that today, using properly formulated materials, carefully thought-out designs, and extensive laboratory and field testing, outstanding results can be obtained from fiberglass reinforced polymer insulators. Both the volume and variety of these modern insulators will certainly grow rapidly in the years ahead, as manufacturers and users together expand the designs and applications into ever-widening fields.

TECHNICAL REPORT LK-864

COMPOSITION OF LOW VOLTAGE POLYMERIC INSULATORS MARKETED BY OUR COMPETITORS FOR INDOOR USE

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Technical Report LK-864

Composition of Low Voltage Polymeric Insulators Marketed by our Competitors for Indoor Use

ABSTRACT

Nine different polymeric insulators obtained from competitive companies were analyzed for aluminum trihydrate and volatile* contents, by means of loss on heating at 400°C, 650°C, 700°C, X-ray diffraction, microscopy and chemical spot tests. It was found that none of these insulators contains aluminum trihydrate and therefore no violation of General Electric's patent took place. Further detailed examination of these insulators is not suggested. However, an eye should be kept on any new polymeric insulators entering the market as a competitive material to GEPOL insulators.

DESCRIPTION OF THE INSULATORS

Most of the nine polymeric insulators were of the indoor bus support type and they are described as follows:

B-1 15-21-27 H. K. Porter - (Red-Cherry color)

B-2 Delta Star - Electric Division, Lynchburg, Va. H. K. Porter Co., Inc. (Gray-bluish color)

B-3 The Glastic Corporation, Cleveland, Ohio 1872-1 - (Red-brick color)

B-4 The Glastic Corporation, (Orange - color)

B-5 Redseal 704

B-6 12-15 Kearney Company, Class A-20, Cat. No. 2411101 - (Grey - color)

B-7 Schwager - Wood - (Brown - color) This was not an insulator, but a kind of protective shield probably for laser light.

B-8 The Glastic Corporation - (Orange - color)

B-9 Rectangular shape, (Red - color), made by Insul.8 Corp. using Glastic 1404 unsaturated polyester resin.

C-1 GEPOL insulator

C-2 Aluminum trihydrate powder

C-3 Aluminum oxide

*Volatile here refers to resins, water and carbon dioxide.

OUTLINE OF THE USED ANALYTICAL PROCEDURES

1. X-ray Diffraction

The X-ray machine is a very useful tool to identify inorganic crystalline compounds from their characteristic peaks. Minor components of a blend in quantities less than 5 wt. % are undetectable and this technique works mostly with very simple blends, as a qualitative method. In instances that peaks of individual components in a given blend are very close, as it was the case with the insulator B-9, the refractive indices of these compounds were used as identification means. Unfortunately the refractive indices of both materials calcium sulfate and calcium silicate were very close and a chemical test had to be used in order to verify the presence or absence of calcium sulfate, and that was done by using barium chloride.

A 5 to 10 grs. sample of the unknown insulator is heated at 650°C for one hour and is finely pulverized, sieved through a 40 mesh sieve, pressed to a plastic cube and exposed to X-ray light. Care must be taken that the ashing temperature does not cause chemical changes to take place in the fillers.

2. Microscope

In cases of glass fillers in the form of fibers or cloth or water-glass, the silicon dioxide is in amorphous shape and therefore the X-ray machine shows no peaks. Amorphous silica in these cases in determined with the aid of the microscope. Refractive indices are measured also in the microscope by using oils of known refractive indices.

3. Loss on Heating

The loss on heating @ 650°C for one hour has been used before to determine resin content in the rods of the Gepol insulators. In this case the only volatiles are the epoxy resin plus glass fiber additives, which average 0.8 wt. % of the glass. In the rods this loss becomes 0.6 wt. % because the rod composition is 75 wt. % glass and 25 wt. % resin. In any insulator there will be some other volatiles depending on the filler type in addition to resin and glass additives. For example water will be volatilized if aluminum trihydrate has been used as a filler or carbon dioxide if calcium carbonate was the filler. Although the conditions 650°C for one hour are not adequate for full conversion of calcium carbonate to calcium oxide with elimination of carbon dioxide, in the presence of resin the exotherm carries the temperature above 650°C. Therefore decomposition of calcium carbonate takes place in the presence of organic combustible material, that would not occur in the absence of the organics.

A better identification of the "volatiles" in cases of carbonate fillers in the unknown insulators was to find the loss on heating at 400°C for two hours and report the loss as resin (plus water if any). The loss on heating at 700°C for two hours presumably represents the sum of resin plus most of the carbon dioxide.

DISCUSSION OF TABLE I

The organic material was not identified but it is believed that B-6 is an epoxy resin, B-3, B-4, B-7, B-8, B-9 are unsaturated polyesters and B-1, B-2, and B-5 could be either one.

During the testing none of the unknowns indicated the presence of aluminum trihydrate or aluminum oxide. Based on the results shown on Table I we can draw the following conclusions:

Insulators B-1, B-4, and B-8 contain calcium carbonate as a filler which decomposes at 650°C or above to calcium oxide and carbon dioxide. However, the two hours heating on 700°C is not sufficient to complete this decomposition reaction and a more accurate method to determine the calcium carbonate should be ignition at 900°C. Insulator B-3 and B-9 contain calcium silicate and calcium sulfate as fillers. Apparently B-9 used gypsum ($CaSO_4.\frac{1}{2}H_2O$) instead of a more hydrated calcium sulfate. In B-2 insulator, probably the filler was water-glass which looses 10-12 wt. % water at above 500°C. Apparently small quantities of calcium carbonate was used as a hardener for the water-glass and its decomposition at above 600°C to calcium oxide and carbon dioxide was indicated as part of the loss. In B-5 insulator the weight stability and the absence of any peak in X-ray diffraction indicated fiberglass. In B-6 case the filler was silicon dioxide probably in the form of sand plus iron oxide as an impurity. In B-7 case, which is not an insulator, but a protective shield, the filler was glass cloth.

From the given explanations, for the fillers studied, the losses on heating at 400°for two hours represent the resin content, while losses at 650° or above represent resin plus water or carbon dioxide. Even the exotherm at 400°C does not fully guarantee that there is not a loss due to decomposition of calcium carbonate. However, if there is such a loss at 400°C, it should be very small.

The loss on heating of C-1 (see Table I) is in agreement with the GEPOL composition and it represents the sum of resin content plus the hydration water of aluminum trihydrate. Since the ashing of C-1 at 650°C or above leads to aluminum oxide, X-ray diffraction analyses of aluminum oxide (pure) or obtained from the ashing of C-1 insulator, as well as of aluminum trihydrate, were performed. The X-ray peaks obtained are characteristic for aluminum trihydrate and aluminum oxide and are entirely different from the peaks of the other fillers of the "B" series insulators and, therefore, a differentiation of the individual compound is possible. Furthermore, the verification of the individual crystalline filler was done by comparing its X-ray peaks with reagent grade compounds having the suspected composition. There is no doubt, therefore, that none of the nine unknown insulators contain aluminum trihydrate or its anhydrous oxide, and that the reported fillers are what the X-ray peaks indicated.

TABLE I

Insulator	Loss on Heating (Wt.%) 2 hrs. @ 400°C	1 hr. 650°C	2. hrs. 700°C	X-ray Peaks	Remarks
B-1	36%	43.5	45.5	$CaCO_3$+CaO (calcium carbonate plus calcium oxide)	At 650°C and 700°C the $CaCO_3$ was partially decomposed to CaO +CO_2. Maximum resin content 36wt.%
B-2	36.6	42	42.2	Glass plus $CaCO_3$ (minor component)	Probably the filler was water glass hardened with $CaCO_3$. Dehydration of water glass is effective at above 490° to remove the 12 wt.% water.
B-3	30.6	43	46	$CaSiO_3$+ $CaSO_4$ (calcium silicate plus calcium sulfate)	Apparently the calcium silicate and sulfate were in hydrate form and lost their water above 400°C.
B-4	22.7	45.5	47	$CaCO_3$+CaO	Similar case to B-1 Maximum resin content 22.7 wt.%
B-5	39.7	37.7	39.9	Glass fiber	Obviously fiberglass Max. Resin content 39.3% and 0.6wt.% glass additives.
B-6	20	20	20	SiO_2 Silicon dioxide (sand)	Max. resin content 20%
B-7	72	73	75	Glass Cloth	Max. Resin content 73 wt.%.
B-8	20	30	47	$CaCO_3$+ CaO	Similar to cases B-1 and B-4
B-9	30	34.5	35.7	Calcium silicate plus calcium sulfate	Similar to case B-3. Apparently the $CaSO_4$ here was in more anhydrous form.
C-1	59	60.5	61.0	$Al2O3$	
C-2	34	34.6	34.6	Al_2O_3	
C-3	None	None	None	Al_2O_3	

POLYMER HIGH VOLTAGE INSULATORS FOR OUTDOOR USE

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INTRODUCTION

Insulators for outdoor high voltage conductors have been available since before the turn of the century. Throughout this time, the material used has been electrical grade porcelain. Today these porcelain insulators are highly regarded and of outstanding quality in terms of their strength and long term reliability, but nevertheless there are some properties of such insulators that can be improved.

There are three basic functions that high voltage insulators must provide: mechanical strength, dielectric strength, and leakage distance. In order to provide this latter, all outdoor insulators use hoods which provide extra leakage distance over that which would be provided by the straight length ("arcing distance") of the insulator itself.

There are, however, a number of additional properties which are also needed beyond these basic ones. Porcelain is heavy, particularly so when present suspension designs require large amounts of metal in order to make connections between the shells. Furthermore, porcelain is notoriously poor in impact strength and easily damaged during manufacturing, shipping, or installation. In order to get desired strength and leakage distance, porcelain suspension insulators are bulky and less than aesthetically attractive when viewed against the sky. Finally, the nature of the material and its processing makes certain desirable complex shapes difficult or too expensive to manufacture. These shortcomings led to a study of polymeric materials as replacements for wet process porcelain insulators for outdoor use.

TRACKING: PROBLEMS AND SOLUTIONS

The earliest trials with polymeric materials indicated that essentially all of them were subject to tracking problems, particularly when contaminated. An excellent discussion of the tracking phenomenon has been reported recently, in which tracking is defined as the decomposition of electrical insulation, caused by the passage of electric current or charge, resulting in the progressive formation (usually tree-like) of a conducting carbon path.[1] This problem is more severe when

moisture or contamination is present, and particularly severe when both are present, as is the case in outdoor insulation. Coastal and industrial areas are notably difficult applications for high voltage insulators, and led to the use of porcelain fog-type insulators in these areas a number of years ago. In the case of polymers, it was found that weathering of the insulators could lead to degradation products which could be as troublesome as airborne pollution.

For some time this tracking problem remained unsolved, but in the mid-1950's the beneficial action of hydrated inorganic materials was discovered.[2] These fillers, particularly hydrated alumina, were found to reduce the rate of tracking of polymers very greatly, especially when used with butyl rubber, epoxy resins, or polyesters. In order to get these benefits, rather large quantities of filler are necessary; at least twenty percent, but usually fifty to seventy percent, by weight of the mixture.

The action of hydrated alumina has been attributed to several factors. Most sources agree now that tracking of polymers is dependent upon rate of formation and rate of removal of carbon. If no carbon can be formed by leakage currents, as in porcelain, then tracking will not occur. Where polymers are used, however, carbon is generally rather easily formed and must be removed at a rate which will prevent its accumulation and consequent current conduction. Three factors have been found important in controlling the rates of formation and removal of carbon in order to prevent tracking. Earlier studies have indicated that certain types of chemical structures are less prone to track than are others.[3] In general those materials which do not contain unsaturated carbon-carbon bonds are most resistant to tracking, while those materials which are not fully saturated, including aromatic structures, are much more apt to track.

Carbon formation therefore may be restricted by the use of proper materials. Its removal when formed, however, is still a problem regardless of the rate at which it is formed. The scrubbing action caused by rainfall in outdoor locations is a help, particularly if the configuration of the insulator itself is such as to promote uniform cleaning by the rain. Unfortunately, in many cases rainfall does not occur in such a driving

fashion as to wash off carbon and other pollution. In these cases it simply moistens the surface and increases the conductivity of the pollution, promoting rather than preventing tracking.

The most satisfactory method available for carbon removal is through oxidation of the carbon to gaseous products which will move away. A limited amount of field experience has indicated to us that coatings which restrict the movement of air to the surface of the polymer insulator will hasten tracking. Silicone greases, which have gained acceptance for use as coatings on porcelain insulators in severe contamination areas, are an example. Used on polymeric insulators, there was no beneficial action by silicone greases, and quite possibly a hastened failure due to tracking. The satisfactory use of polymeric surfaces immersed in oil would tend to deny this conclusion, but the latter is probably explained by the increased resistance to electrical current flow caused by the oil and the protection from the elements inside the sealed container, such as a transformer can.

Oxidation by air, however, is much too unsatisfactory to depend upon as a method of carbon removal. The use of hydrated fillers appears to provide the most satisfactory answer to date. The heat developed by leakage currents, which causes carbon formation, is sufficient to release the water of hydration. This water in turn apparently reacts with the carbon to form carbon monoxide and hydrogen in what is commonly known as the "water gas" reaction. Although any hydrate might be considered satisfactory, it is necessary to use one which will not decompose during manufacture of the insulator or at normal service temperatures. Hydrated alumina is quite satisfactory in this respect. In addition, the alumina formed by dehydration has been suggested as serving a catalytic function in the water gas reaction making hydrated alumina particularly useful. The use of other fillers in comparison with hydrated alumina for various epoxy resin formulations has been the subject of a number of papers. For example, Billings and Humphreys in England have recently presented data based on two standard insulator designs, a straight rod and a post type, which points out the improvements possible through the use of hydrated alumina in a variety of epoxy formulations, compared to a series of other fillers.(4)

A third factor in the prevention of tracking is the proper design of the insulator's shape. In order to prevent leakage currents from becoming excessive, it has been the practice in porcelain to provide extensive leakage distance, much of which is "protected", or cut into the lower surface of the overhanging hood so that a series of "petticoats" are formed. When hung in the normal vertical position, this leakage distance does not become directly wetted during rain and therefore provides a high resistance to leakage currents. Attempts have been made to utilize this approach in designing polymer insulators. However, as will be discussed below, protected leakage distance has not been a satisfactory answer in polymer insulator designs in prevention of track formation.

The further importance of insulator design can be seen by considering Whitehead's contention that tracking propagation is maintained only by continuous average leakage currents in the track in the range of 100 μA.[5] Any design which will concentrate leakage current in one narrow path, rather than diffusing it uniformly over the surface of the insulator, will enhance the formation and propagation of a track. Not only such obvious problems as parting lines from molds need to be considered in this way, but also other factors more difficult to predict, such as the manner and non-uniformity of deposition of airborne pollution and its subsequent moistening by rain, which will tend to produce low resistance paths along which the leakage current will concentrate.

The application and testing of the above principles in the development of the present GEPOL® insulator (General Electric's proprietary polymer insulator) required thirteen years, during which some of the above principles were developed, either as a part of the program or by others following related studies. Much of this time was required for long term field testing.

MATERIALS

The polymeric materials available in the mid-1950's were extensively studied in our laboratories and finally narrowed to epoxy resins and butyl rubber for further development work. Most other contenders failed in some essential property---poor weathering, poor tracking, too easily contaminated, or poor

electrical characteristics. The Insulator Department of the General Electric Company decided to concentrate on epoxy resins, for they could be handled by casting techniques for both large and small shapes. Butyl rubber, on the other hand, though convenient for manufacturing small parts, does require large molding presses and manufacturing becomes much less attractive for large pieces.

Only the Bisphenol-A epoxy resins were available at that time, and were used for all the early work. The most satisfactory curing agents for electrical purposes generally resulted in brittle products with poor impact strength and low temperature performance. Ultimately these problems were solved by use of flexibilizers.

The use of hydrated alumina in the high proportions needed for effectiveness in reducing tracking reduces the mechanical strength of the casting, as does the flexibilizer. In order to gain sufficient strength for suspension use, it was necessary to use a central fiberglass rod as the load carrying tension member. This was beneficial in an additional way: a long enough rod could be used to eliminate the need for metallic connecting hardware between short modules as is done with porcelain. With such designs, it became possible to make one long unit with hardware needed only at each end of the insulator. The normal cap and pin type porcelain suspension insulator uses approximately 4.2 pounds of metal on the two modules used for 15 KV service. A single GEPOL unit used to replace this pair of porcelain units requires only 1.8 pounds of metal. For a 115 KV case, the savings becomes even more noteworthy: the porcelain requires 26.4 pounds of metal for a 20,000 pound rating string of seven modules, while the GEPOL insulator replacement requires only 4.6 pounds.

FIRST FIELD TRIAL

The first GEPOL insulators made for field trials were designed for 69 KV use. Basically the hood design was that of conventional porcelain, except that undercuts in the hoods were not used because they are not practical from a casting mold viewpoint. The central fiberglass rod extended beyond the ends of the track resistant body. The

socket-type hardware was held by epoxy adhesive to the ends of the rod. The hoods were molded in one integral piece around the fiberglass rod, were angled on their top surface to allow rain to drip off, and were flat on their lower surfaces, as shown in Figure 1. The total leakage distance provided by the nine hoods was sufficient to give 620 volts/inch when used in 69 KV service (39.8 KV to ground). The results of laboratory testing of this unit have been reported.[6] All the tests made showed the unit was at least equal to the standard porcelain ratings.

Over fifty of these insulators were installed in utilities in Massachusetts, in Maryland, and on the Florida coast in 1959. After seven years, those in Florida were exposed to a storm which deposited salt on them, soon after which they flashed over frequently, tracked, and were removed from service. All the Florida units were in a vertical position. The rest of the 69 KV units are still in service, with only one vertical unit in Maryland showing a slight amount of tracking after eight years and no damage to the units in Massachusetts.

SECOND FIELD TRIAL

The second field trial was with GEPOL insulators designed for 115 KV service. In these units, the design of the central rod was altered to provide increased mechanical strength in tension. The socket type hardware held in place over the ends of the rod by adhesive was replaced by a newly designed rod. This new rod used loops of fiberglass at each end, and the loops fit over ears on the hardware, which was partially embedded in the track resistant body of the insulator. The shape of the hoods themselves was modified to the extent that both upper and lower surfaces were angled and because of the higher voltage, twelve hoods were used to provide sufficient leakage distance. As a result, the voltage stress was 790 volts/inch when used on 115 KV service (66.5 KV to ground). The results of laboratory tests on this unit have been previously reported.[7] The insulator and its porcelain equivalent are shown in Figure 2.

Field testing of this model was educational. More than 1,500 units were put into service in 1963 at more than sixty utilities scattered throughout the country. In many critical contamination areas, tracking failure began to occur in periods

as short as six months on vertical units, though after four years the horizontal units have been excellent in resisting tracking.

Failure on the vertical units has occurred in several ways. Quite frequently the initial sign of failure has been puncture through the body of the insulator to the embedded hardware. This has been believed partly due to excessive voltage stresses in that area, possibly because of voids in the casting, in which corona has occurred. Once a puncture occurs, there is localization of leakage currents and tracking or erosion of the epoxy body takes place, leading eventually to failure of the unit.

However, it is not likely that casting voids are the only explanation for failed units, or else failures would be expected in the horizontal position as frequently as in the vertical. Wetting and cleansing during rainfall is more uniform in the horizontal position, and helps prevent alternating wet and dry bands from occurring on the surface of the insulator. Dry bands on a damp insulator lead to spark scintillation and burning damage. Undoubtedly such dry band formation under hoods on contaminated vertical insulators has localized leakage currents and set up unequal stresses. When this occurs in the area of the embedded hardware in the vertical units, tracking and erosion tend to localize there and soon erode through to the hardware.

Another failure mode was isolated tracking paths randomly distributed along the length of the insulator. These too are believed to be caused by stabilization of wet and dry bands in the vertically hung insulators, with the bands probably caused by non-uniform deposition of contaminants, aided by non-uniform wetting. Supporting this belief is the fact that insulators in those areas with high rainfall have been most satisfactory in performance, presumably because they are most readily washed clean. For this reason, protected leakage distance does not appear to be desirable on polymer insulators.

FIRST COMMERCIAL POLYMER INSULATOR

Based on the experience gained with the 115 KV insulators, a 15 KV model was designed at the end of 1965. The design is shown in Figure 3, compared to the porcelain equivalent. By

this time, cycloaliphatic epoxy resins were available and gaining popularity for electrical and outdoor applications. The resins themselves have greatly improved track resistance over the earlier Bisphenol-A epoxy resins, presumably because they have eliminated the track-prone aromatic ring. However, our experience has been that these new resins are still amenable to further improvement by use of hydrated alumina. With high levels of hydrated alumina in cycloaliphatic resins, it appears that tracking can be eliminated under even relatively severe tests, such as the salt-fog. At worst, only mild erosion seems likely to occur in these systems, except perhaps under extremely severe laboratory conditions. At this time we have not experienced any tracking problem on 15 KV test units in outdoor exposure, even in accelerated tests with 1,000 volts/inch of leakage distance in the vertical position at a highly contaminated site. In normal use (7.8 KV to ground), the insulator is exposed to only 560 volts/inch of leakage distance.

The 15 KV unit reverted to the original socket type hardware fastened by adhesives to the protruding ends of the fiberglass rod. This step was taken to eliminate the puncture problem noted above with partially encapsulated hardware on the 115 KV unit. The rod is modified from that used on the 69 KV model, however, in that a wedge is placed in the ends of the rod to produce a flare. Two purposes are served by this flare: it increases the area for bonding; and it provides insurance that should the adhesive bond to the rod fail after a number of years in service, the rod will not slip out of the hardware. The design of this wedge can be seen in Figure 4.

The application for 15 KV suspension insulators, porcelain or polymer, is essentially always horizontal, using conventional American line construction practices. This is because the conductors at this voltage level are normally carried on upright pin type insulators except at deadends or angles where a horizontal suspension insulator is used. As noted above, polymer insulator horizontal applications have consistently been successful, even with insulator materials and designs less satisfactory than the ones now in use.

To date over three hundred utilities have purchased some tens of thousands of these 15 KV GEPOL insulators since they

were first introduced commercially in early 1967. No tracking or erosion problems have been reported from any installation. Reduction of metal joints has eliminated problems of radio noise, which is of particular interest to the users, as are the light weight and unobtrusive design overhead . A comparison of the GEPOL insulator properties with code requirements for 15KV service is shown in Table I.

REMAINING DEVELOPMENT AREAS

One of the chief areas that is still unknown is the success that can be expected of present materials and designs at higher voltages, particularly in the vertical position. Although the normal use of suspension insulators for distribution voltages (through 34 KV) is in the horizontal position, most of the suspension insulator market is at higher voltages and is for units in the vertical position. This problem is under study now in our laboratory and at several outdoor sites. Currently there are 115 KV GEPOL insulators with hood design identical to the earlier 115 KV but with hardware similar to that of the 15 KV model in field tests in both horizontal and vertical position. The material used in these test units is based on cycloaliphatic epoxy formulations which have proved satisfactory in the 15 KV insulator. In addition to work on 115 KV units, outdoor test site experience mentioned earlier with the 15 KV model in the vertical position is being continued.

From an overall viewpoint, laboratory evaluation of polymer materials and insulators has not been entirely satisfactory. In the earliest work, most tests were done on samples of material, by a variety of standard methods. Today, the most satisfactory approach of that kind is the inclined-plane test (ASTM-D-2303-64T), but a number of other tests are also available, including the dust-fog test and the IEC tracking test. Unfortunately, as has been discussed above, insulator design plays an important role, and tests based on sheets or slabs of material are not necessarily indicative of insulator performance.

Laboratory tests on actual insulators have been made in the GEPOL program by means of wet tests at voltages near the flashover voltage, and by salt-fog testing. The former test will

generally give results in several hours similar in appearance to those seen in several years of field experience, but has not always been accurate in ranking insulators of different formulations. It has the additional possible objection of being carried out at voltages far above the service voltage and therefore unrealistic of field conditions. The salt-fog test generally does not damage cycloaliphatic resin insulators of our latest formulations, even in thousands of hours of exposure at service voltages. Tests have been run in our laboratory now for over 4,600 hours of salt-fog exposure with no damage, or failure to hold voltage, on the 15 KV model. The equipment available does not permit higher voltages to be used, but we have cut down the length of the 15 KV model, which increases the voltage stress. After 4,600 hours, no damage has occurred on these cut-down test insulators at voltage stresses up to 950 volts/inch of leakage distance, the most severe stress we have tested in salt-fog. Even normal stresses of 600 volts/inch shatter ceramic units in this test in 2500 hours. An interesting explanation has been made of these results. Douglas and Scarisbrick have suggested that increasingly severe tests, such as the inclined plane, place materials in their proper order of track resistance. On the other hand, constant condition tests, such as our wet test or salt-fog test, tend to assess life, but do not necessarily place various materials in proper order.[1] In any case, the constant condition tests require long periods of time for answers to be obtained when materials as good as those available today are used.

Obviously then none of these tests is entirely satisfactory for study of new insulator materials and configuration, except possibly the inclined plane for rapid screening of new materials. We are presently working with tests which add organic material to the sprayed-on salt contaminant in a salt-fog test. The organic material appears to allow tracking to occur more readily, probably because the contaminant itself is subject to carbon formation. Such organic contaminants are probably similar to contaminants that are experienced in industrial pollution areas. By using some very severe conditions at service voltage we can cause tracking to take place more readily. Current programs are aimed at determining, by means of this test, the effects of various insulator configurations upon track and erosion resistance in both vertical and horizontal positions.

CONCLUSION

Polymer insulators for high voltage outdoor use are now working satisfactorily in horizontal applications after periods of as long as eight years of actual service on utility lines. Newer materials and design configurations have provided satisfactory service in laboratory and outdoor tests for periods up to eighteen months and are still continuing. Experience to date indicates that properly formulated and filled cycloaliphatic epoxy resins have eliminated tracking in the horizontal position under field conditions, but erosion may be a problem in longer periods of time at the higher voltages, particularly in the vertical position. More work is needed to answer this erosion question, as well as to find a suitable correlation between short-time laboratory tests and long-term field life.

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TABLE I

TYPICAL MECHANICAL AND ELECTRICAL DATA FOR
15 KV POLYMER INSULATOR VERSUS CODE REQUIREMENTS

	GEPOL INSULATORS	15 KV SYSTEM
Leakage distance, in.	14	12
Dry arcing distance, in.	8¼	6¼
RIV test KV RMS to ground	15	15
RIV Max. Microvolts at 1000 KV	50	100
Impulse F.O. voltage, KV, Pos.	140	130
Impulse F.O. voltage, KV, Neg.	165	155
Low Frequency F.O. voltage, KV, Dry	100	80
Low Frequency F.O. voltage, KV, Wet	60	45
Low Frequency Puncture voltage, KV	150	115
Impact Strength, inch-pounds	Virtually Indestructible	---
Net weight, pounds	3¼	---

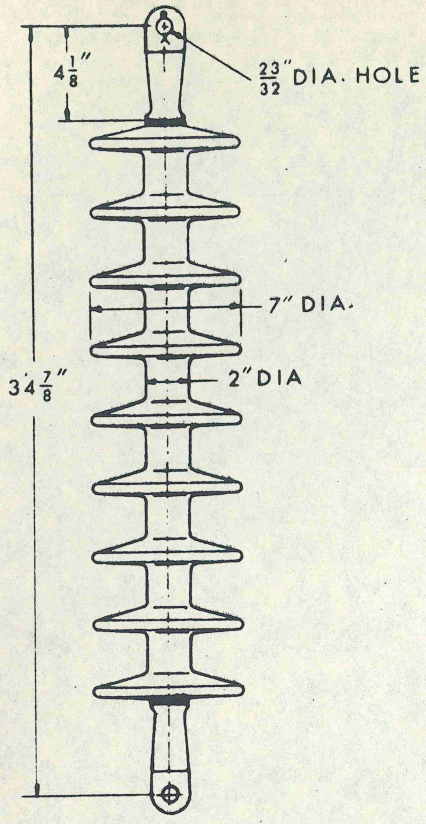

Fig. 1 - 69KV Polymer Suspension Insulator

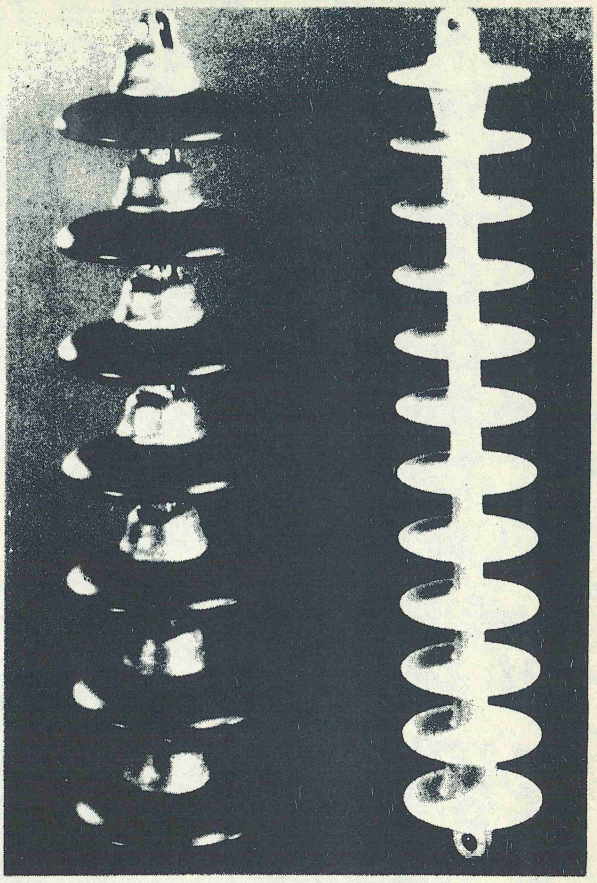

Fig. 2 - 115KV Insulators - Porcelain and Polymer

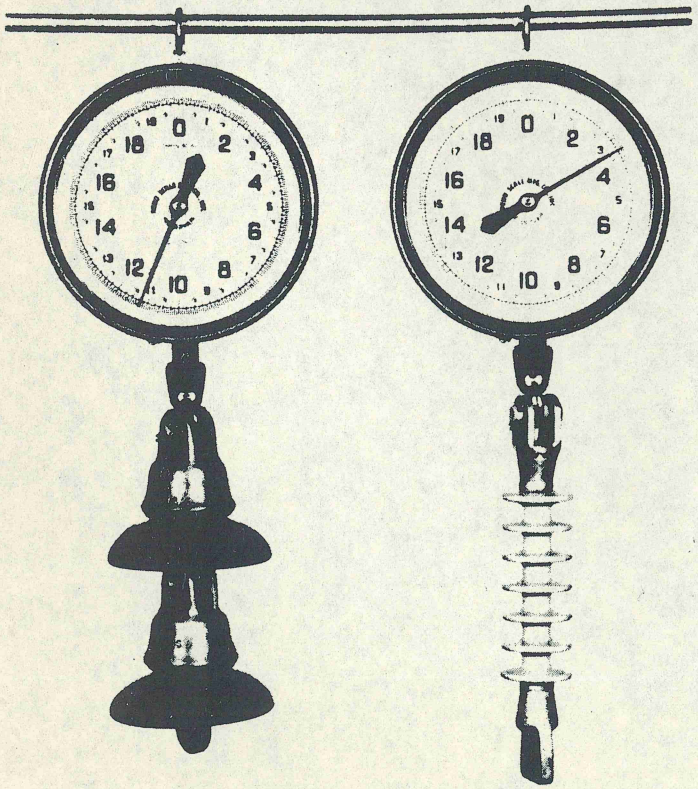

Fig. 3 - 15KV Weight Comparisons - Porcelain and Polymer

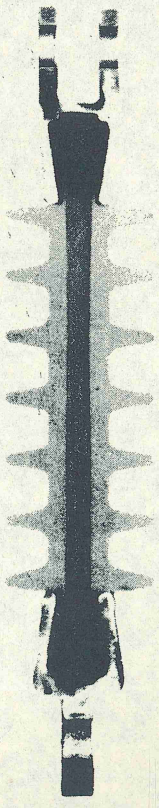

Fig. 4 - 15KV Polymer Insulator Cross-section

OUR FAMOUS FIRSTS IN THE FIELD OF ELECTRICAL INSULATION

1893	First Wet Process Porcelain Insulator
1896	First 60 KV Pin Type Insulator
1896	First Triple Petticoat Insulator
1897	First Helmet Type Insulator
1904	First Suspension Insulator
1904	First High Voltage Laboratory
1908	First Clevis Type Suspension Insulator
1908	First Radio Insulator
1908	First Nicholson Arcing Ring
1909	First Switch Insulator
1911	First Switch Insulator for High Voltage
1920	First Stack Type Switch Insulator
1929	First Major Improvement in Glaze
1931	First to Reglaze over the Sand Grip
1932	First Noiseless Pin Type Insulator
1934	First Hi-Top Insulator
1935	First Compression Glaze
1938	First Compression Sand for Cement Grip
1939-45	First Mat Glaze for Metallizing Porcelain for Hermetic Sealing
1939-45	First Vacuum Pressed Steatite
1947	Newest and Most Modern Ceramic Research Laboratory
1953	First Mechanized Manufacturing for Line Type Insulators
1955	First High Strength Ceramic Body for E.H.V. Applications
1956	First Ball and Socket Type 36,000 Lb. Suspension Insulator
1956	First 10" - 25,000 Lb. Suspension Insulator for 4-3/4" or 5" Spacing
1957	First 650 KV BIL Switch and Bus Insulator Stack
1957	First Combination Stacking Unit for Economical Strength Grading
1958	First Color Coding for Suspension Insulators
1958	First Spray for Silicone Grease - INSULJEL
1959	First Complete Line of Extra High Strength Stacking Switch Insulators
1959	First Rugged 6" Distribution Insulator
1959	First Polymer Suspension Insulator
1960	First Insulator String Designs for Large Scale 500 KV Line in U.S. - Penelec
1961	First Insulator String Designs for 770 KV Line - EHV Pittsfield
1963	First Polymer Insulator Laboratory and Pilot Shop
1964	First Polymer Insulators for EHV Station Equipment
1965	Installation of World's Tallest Kiln for EHV Porcelains
1966	First Shrouded Clevis Hardware Fitting for EHV Assemblies
1967	First Polymer Distribution Deadend Insulator
1967	First Catalog of Standard EHV Assemblies
1967	First (Joint G.E.-Bethea) D.C. - E.H.V. Hardware System
1968	First 80,000 Lb. Suspension Insulator in the U.S.

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GENERAL ELECTRIC

TECHNICAL INFORMATION SERIES

Title Page

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SUMMARY

A technical paper presented at the Insulating Materials and Dielectric Behavior Technical Conference, Research and Development Center Auditorium, The Knolls, Schenectady, New York on November 13, 1968.

The evolution of the design and development of the General Electric Insulator Department's GEPOL high voltage insulators for transmission and distribution lines is covered from 1959 to the present. Many of the primary principles that should be applied in using polymeric materials for this application are covered. Results of field trials are presented. The various laboratory tests used to evaluate the antitracking characteristics of the organic materials used and the insulators developed are discussed.

KEY WORDS

INSULATORS, GEPOL

INFORMATION PREPARED FOR --

TESTS MADE BY --

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COMPONENT Insulator Department; R&D Center

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DEVELOPMENT OF ANTITRACKING GEPOL® HIGH VOLTAGE INSULATORS

INTRODUCTION

The Insulator Department has actively pursued a project to develop a suitable material which could replace porcelain as an insulator for high voltage outdoor applications since 1954. The principal effort has been directed at finding such a material and utilizing it in the development and design of insulators for use on high voltage transmission lines and on distribution lines. (FIGURE 1)

For all these many years there had been only two materials that would meet the exacting requirements for insulation for high voltage outdoor applications, porcelain and glass. Porcelain has by far been the principal material used in this country. It has served us well. But in order to cope with modern-day requirements an even better material is required, a material which is as rugged as porcelain but which is lighter and which can be formed and molded and easier manufactured and applied; one that is more versatile for mechanical as well as electrical applications.

Replacing porcelain is a difficult task. The material must be able to withstand both mechanical and electrical stresses for thirty to fifty years without attention. It must be able to take innumerable thermal cycles from -40°F to 160°F without damage. It must withstand the ultraviolet light of tropical exposure, the atmospheric contamination of all outdoor exposures without deterioration, and the mechanical shock of wind and ice loads in bitter climates. But probably the most difficult characteristic it has to meet is that it must not burn, track or erode in service under the worst conditions of contamination and moisture. And we must not lose sight of the fact that as a product, insulators made of this material must either offer such superior advantages over porcelain that our customers will be willing to pay for them, or they must be competitive with insulators made of porcelain.

Realizing that all organic materials can be made to track or erode, first came the search for a suitable antitracking material. Literally hundreds of formulations were investigated. Although the antitracking characteristics were important, many other characteristics also had to be evaluated. Finally, in 1957, a modified epoxy type polymer showed considerable promise as an antitracking material. This basic formulation used to make insulators later became the General Electric Polymer, or GEPOL, insulators.

FIRST FIELD TRIALS

The first insulators using this material were designed for use on 69 KV transmission lines. (FIGURE 2) Economics, as well as other factors, dictated a design far different from the conventional suspension insulators used for this application, although the long experience with porcelain also played an integral part. The polymeric material had little mechanical strength compared with porcelain, therefore, a fiberglass rod 15/16" in diameter was incorporated as the

load bearing member. Suitable metallic end fittings were designed so that a tapered, locked-in assembly could be made using an epoxy adhesive. The mechanical strength rating was 15,000 lbs.

For electrical performance in outdoor service, both the arcing distance and the leakage distance are important factors. In this first design, the polymer insulator had about the same arcing distance and leakage distance as an equivalent string of porcelain suspension insulators. If it is assumed that there is a uniform stress across the insulator, the surface stress would be 625 volts per inch. Under actual operating conditions, particularly in contaminated areas, the unit stress will be much higher.

Fifty-four insulators of this design were placed in service in three locations --- in Massachusetts, Maryland and Florida. (FIGURE 3) The first two sites were relatively clean areas. The third was a highly salt contaminated area. From 1959 to 1966, these insulators were in service and showed no sign of any deterioration. In the fall of 1966, the majority of the insulators at the Florida site began to burn and track and all were removed from service. (FIGURE 4). It should be noted here that all of these insulators were in a vertical position.

In 1966 one of the eighteen insulators in the Baltimore area showed a small area that had tracked. (FIGURE 5) Other insulators exposed to the same conditions have shown no sign of deterioration as of October, 1968. No failures have been reported in the Massachusetts site.

SECOND FIELD TRIAL

In 1962, based on the then perfect performance of the first field trial begun in 1959, a decision was made to review the design of the 69 KV insulator, and design an insulator for 115 KV service with a mechanical strength of 20,000 lbs. The review of the 69 KV design indicated that it was probably better to revise the end hardware so that a fiberglass loop could be used as the load bearing member for better mechanical stability. (FIGURE 6) A technique for making a suitable fiberglass loop was developed and the loops were made at the Insulator Department. In this particular design, it was necessary to encapsulate a portion of the metallic end fittings so that the fiberglass would not be exposed. (FIGURE 7)

The line-to-ground voltage for a 115 KV line is approximately 66 KV. This results in an electrical surface stress of 780 KV/in., again about the same as porcelain.

A very large scale field trial was made, using this design of the insulator, a large proportion of the insulators seeing service in abnormally highly contaminated areas. Approximately 1700 insulators of this design were placed in service in locations served by about seventy utilities in the United States. The first of these insulators went into service in the fourth quarter 1963.

First field failures were reported on units having been in service about six months. Failure has occurred principally on those units which were installed in the vertical position. A large majority of the failures appeared to have been initiated by a puncture through the material at the point where the hardware was encapsulated, which started tracking and burning from the exposed fiberglass rod (FIGURES 8 and 9). A few showed isolated tracking paths on the surface. A large number of insulators of this design still remain in service in the horizontal position without apparent damage.

FUNDAMENTALS LEARNED

These two field trials have been quite meaningful. We have learned some fundamentals that we can use:

1. An even better antitracking material is needed (we now have one).
2. Metallic end fittings should not be encapsulated in the cast material.
3. Electrical surface stress is important, particularly under damp contaminated conditions.
4. "Protected" leakage distance should be avoided. The insulator should be as washable as possible.
5. Possibly a corollary to No. 3 above, concentration of current on the surface should be avoided. An ideal insulator has a core diameter to outside diameter ratio of 1.
6. Corona should be avoided.
7. Insulators perform better when in a horizontal position.
8. End contour is important to avoid high stresses.
9. A more realistic laboratory tracking and erosion test is needed so service life can be more accurately predicted.

ELECTRICAL SURFACE FAILURE

Referring to the requirements for a better laboratory test, a great deal of work has been done in this area, much of it at the R&D Center. It has been recognized that a serious field condition arises when scintillation and short arcs appear directly on the surface of the contaminated polymer insulator. Uneven contamination or wetting of the surface produces areas of higher conductance through which the leakage current flows with relatively little voltage drop but in the intervening drier areas of higher resistance the voltage breakdown of the air is exceeded and small surface arcs result. These arcs, close to the surface, may produce, in time, either tracking or erosion of organic insulating materials. The formulation of the insulating material as well as the geometry of the insulator and its associated hardware markedly influence both the nature and the extent of the tracking and erosion.

TRACKING AND EROSION TESTS

A number of tests have been developed to evaluate the tracking and erosion resistance of materials and of complete insulators. Some of these tests have been used for complete devices such as insulators, while some tests have been used for both materials and devices. The salt water-drop test was devised first by the Detroit Edison Company and modified in Europe, where it is now used extensively. Unfortunately, the best track resistant materials cannot be evaluated with the drop test. Various types of salt-fog tests have been developed but none of these, in a reasonable time, can successfully evaluate the tracking and erosion characteristics of the best tracking resistant formulations now available. The dust-fog and the inclined-plane tests were developed in General Electric to evaluate the best track resistant materials. While the dust-fog test is still used to some extent, it has been largely supplanted by the better controlled and rapid inclined plane test. Unfortunately, the two tests are not suitable for evaluating complete devices.

(FIG. 10) A salt-sugar spray test was recently developed which has successfully evaluated the effect of geometry in GEPOL insulators made with the best tracking resistant plastic formulations. Normally the test is conducted inside a test chamber to confine the spray but, for the purpose of obtaining a photograph, the sprays were set up outdoors where the spray-fog and steam would not obscure the action on the insulator. The concentration of salt and sugar, as well as the volume of the spray, can be changed to vary the intensity of the test and also to achieve the critical conditions necessary to produce surface scintillation and arcing. The pattern of the spray is adjusted so that a selected portion of the insulator receives somewhat less spray than the rest of the surface so that scintillation is promoted.

The differences in the resistance to erosion of four different geometries of a 34 KV GEPOL insulator are shown in Fig. 11. When a hood (skirt) is located close to the hardware, it may be eroded rapidly. When it is moved back, erosion takes place more slowly and tends to erode the straight portion of the insulator.

(FIG. 10) The salt-sugar spray test can be made very severe, particularly at higher voltages. While the salt-sugar spray test does permit rapid evaluation of different insulator geometries, it is strictly a comparison test and cannot be used quantitatively to evaluate expected life in service. In fact, further development of the test is needed so that the voltage range can be increased and the severity of the test more easily controlled.

LIFE IN SERVICE

While laboratory tests are useful for comparison of material and design, actual operating experience is the final criterion. The conditions of service vary widely. The amount and nature of the ionizable and organic contamination differ from place to place, as does the amount of fog and rain. Sunlight and chemicals may tend slowly to degrade the plastic surface of the insulator and thereby also affect the resistance to tracking and erosion after subsequent contamination. Thus, the evaluation problem is very complex and difficult.

Fortunately, it is possible to use the results already obtained in the field, together with laboratory tests on old and new insulators, to gain a considerable degree of assurance about the performance to be expected with the new GEPOL insulators.

CURRENT GEPOL INSULATORS

(FIGURE 12) With these factors in mind, we have redesigned the 115 KV insulator. This insulator has an arcing distance of 36-1/4 inches and a leakage distance of 120 inches, which yields a surface stress of 550 volts/inch. The material has been changed from a bisphenol-A type resin to a cycloaliphatic resin which, in itself, is a much better antitracking resin. Even this is improved by the addition of hydrated alumina. We feel our chances of success are greatly improved with the new material and the redesigned insulator. Field trials are necessary to confirm our feelings.

We have, however, applied these materials and principles in the design of a small distribution insulator (FIGURE 13). About 25,000 of these have been sold and shipped to some three hundred different utilities. This insulator is normally used in the horizontal plane and is stressed to 560 volts/inch of leakage distance. The first of these insulators was shipped in February 1967 and we have had no reports of any burning, tracking, or eroding.

We have also completed the design and laboratory tests on an insulator for 34 KV applications (FIGURE 14). Similar in design to the 115 KV and the 15 KV insulators, but with characteristics suitable for this application, the insulator will have a surface stress of 580 volts/inch of leakage distance. We are currently beginning a field trial with this insulator in about twenty-five locations throughout the country.

The authors wish to acknowledge the many contributions to this program which have been made by Frank Nichols, Senior Chemist Polymeric Application, DT Materials Laboratory, Commercial Transformer Department, Pittsfield, who has been closely associated with this program since its inception.

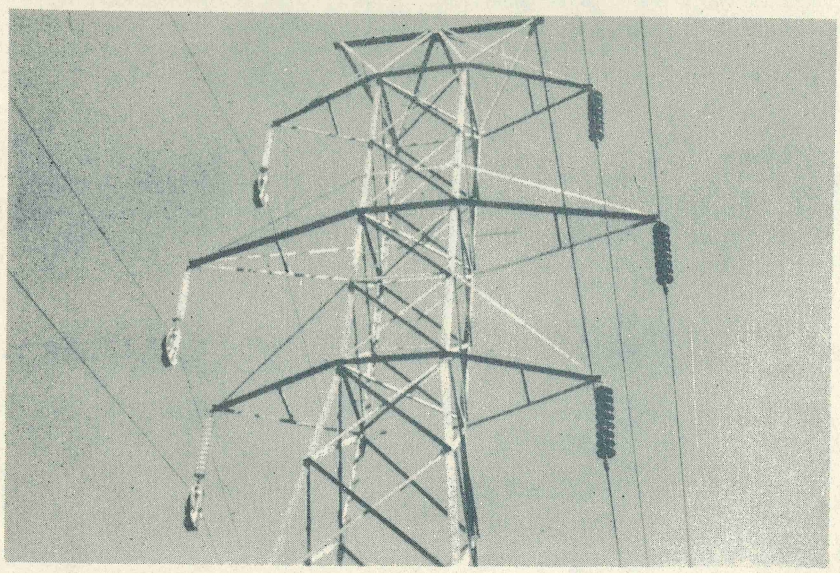


Figure 1. GEPOL and porcelain insulators on a 115 KV transmission line.

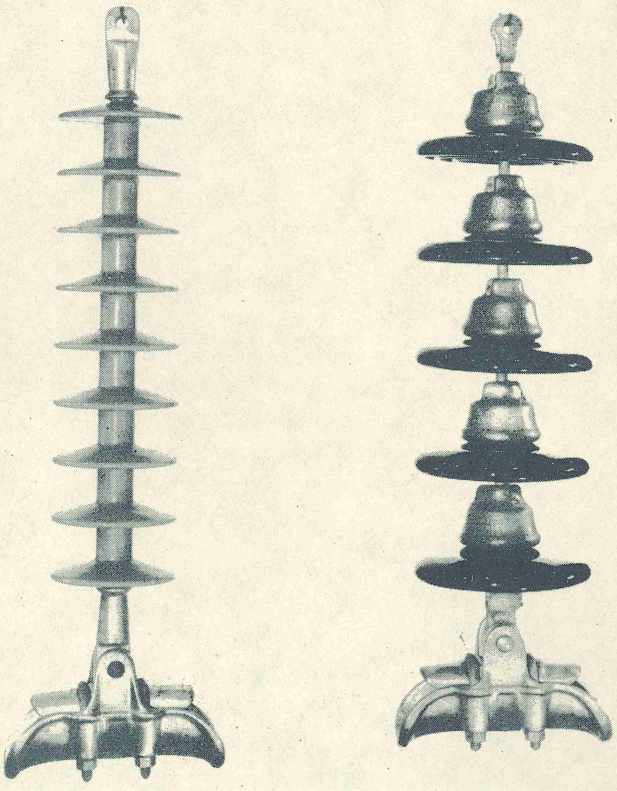


Figure 2. The 69 KV GEPOL insulator and its porcelain equivalent.

Figure 3. Test site on the east coast of Florida.

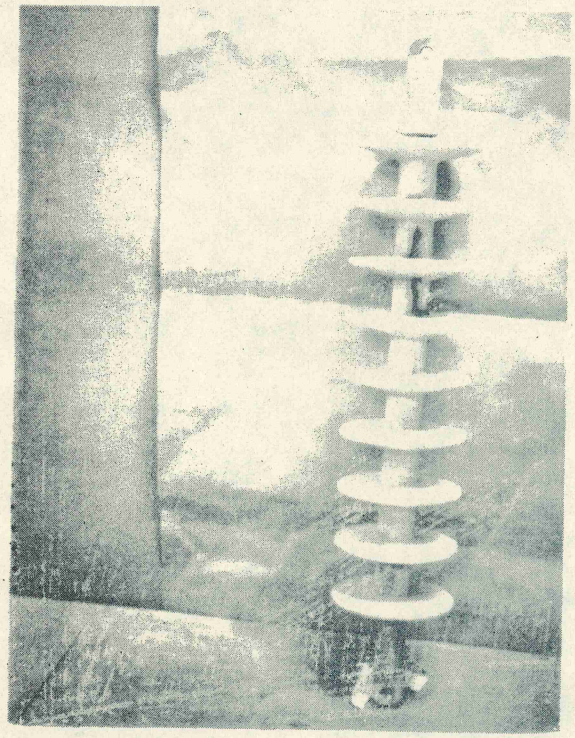


Figure 4. 69 KV Insulator after seven years of service in a salt contaminated area.

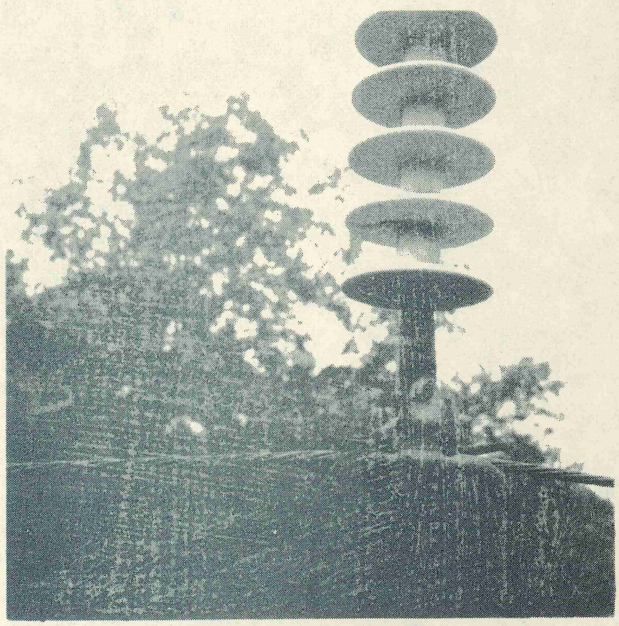


Figure 5. Surface tracking on the 69 KV insulator in the Baltimore area after nine years of service.

Figure 6. The fiberglass load bearing member of the 115 KV insulator.

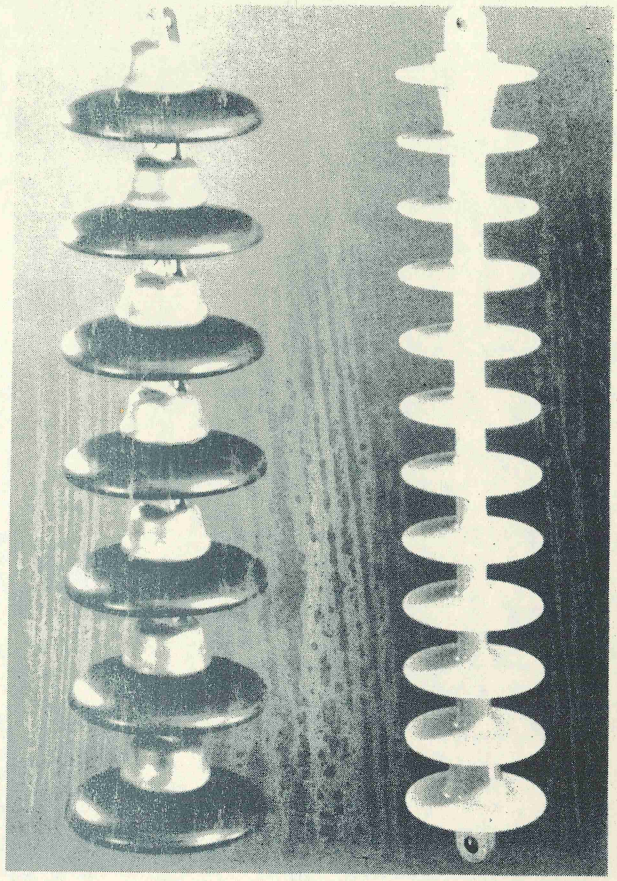


Figure 7. The 115 KV GEPOL insulator compared with its porcelain equivalent.

Figure 8. The 115 KV GEPOL insulator showing the initiating puncture failure through the sidewall.

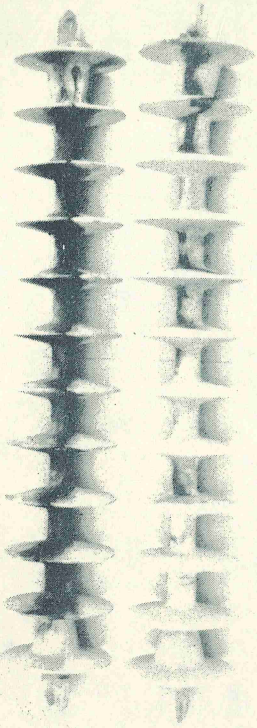


Figure 9. Extreme type of failure while in service in a highly contaminated coastal area.

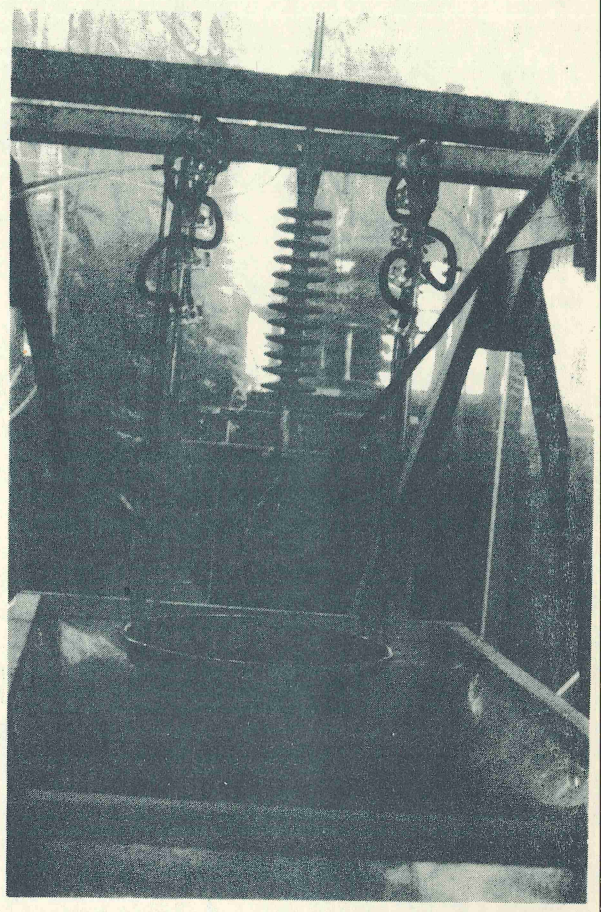


Figure 10. The salt-sugar spray test as run in the R&D Center on a 34 KV GEPOL insulator.

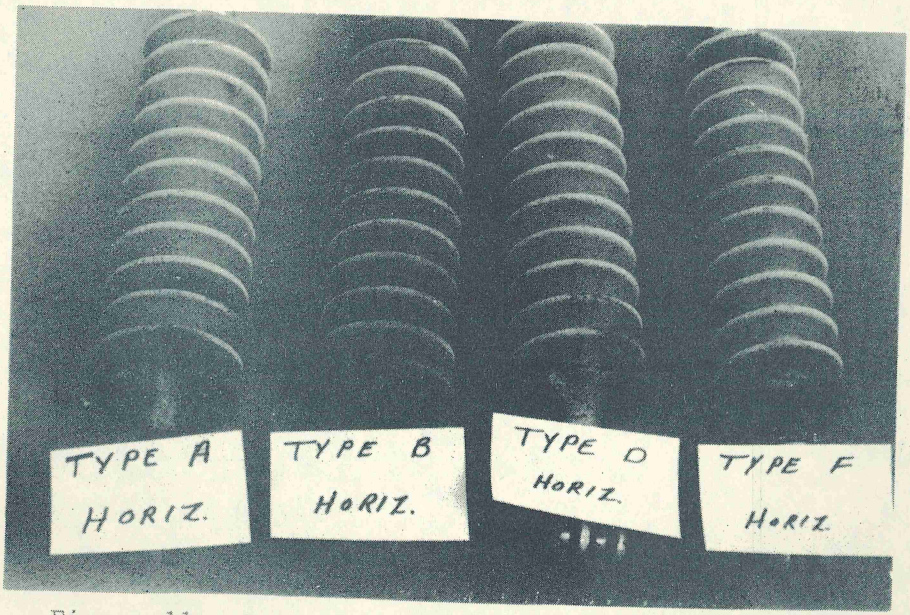


Figure 11. Four different designs of a 34 KV GEPOL insulator after tests in the salt-sugar spray test cabinet

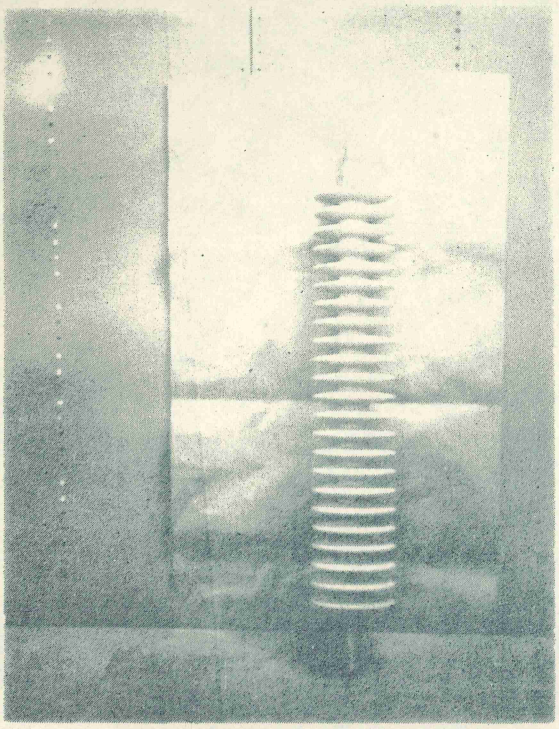


Figure 12. The latest experimental design of the 115 KV GEPOL insulator.

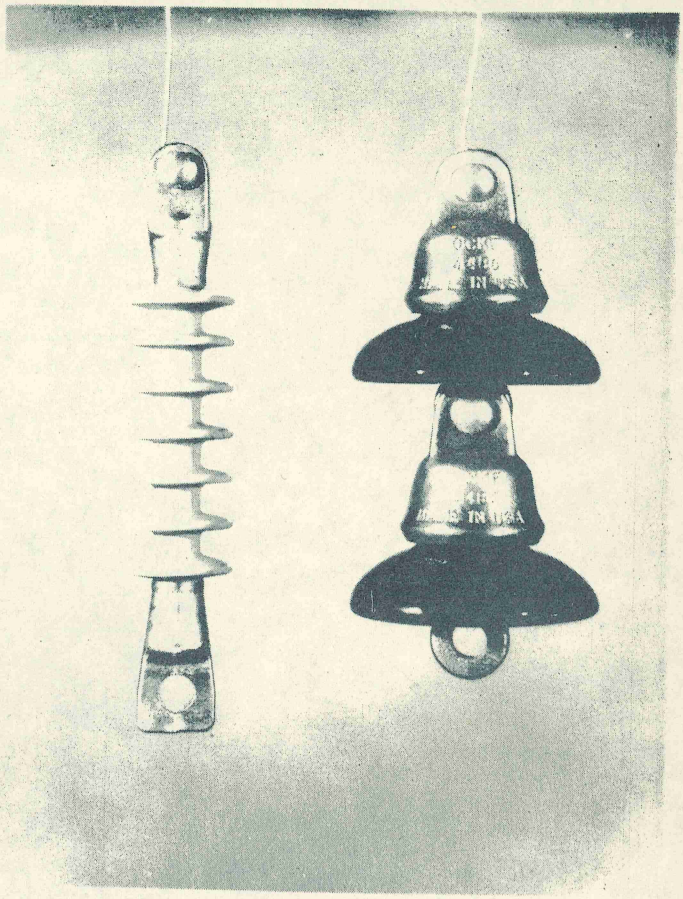


Figure 13. The 15 KV distribution GEPOL insulator compared with its porcelain counterpart.

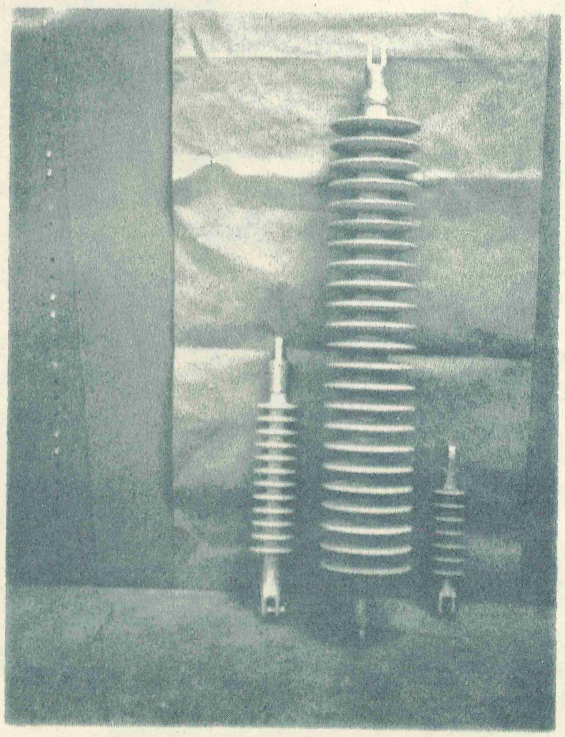


Figure 14. On the left is the 34 KV GEPOL, which is compared with the 115 KV and the 15 KV designs.

ompared to porcelain
t ratio

In Tables 3 and 4, multiple strings of porcelain insulators are required to match working strengths with Hi*Lite. The weight of yoking hardware must be added to the weight of the insulators for a realistic comparison. Since there is some choice in yoking methods, a specific weight figure is not practical. In lieu of this, an arbitrary weight of 100 pounds has been added to double strings, and 300 pounds to quadruple strings.

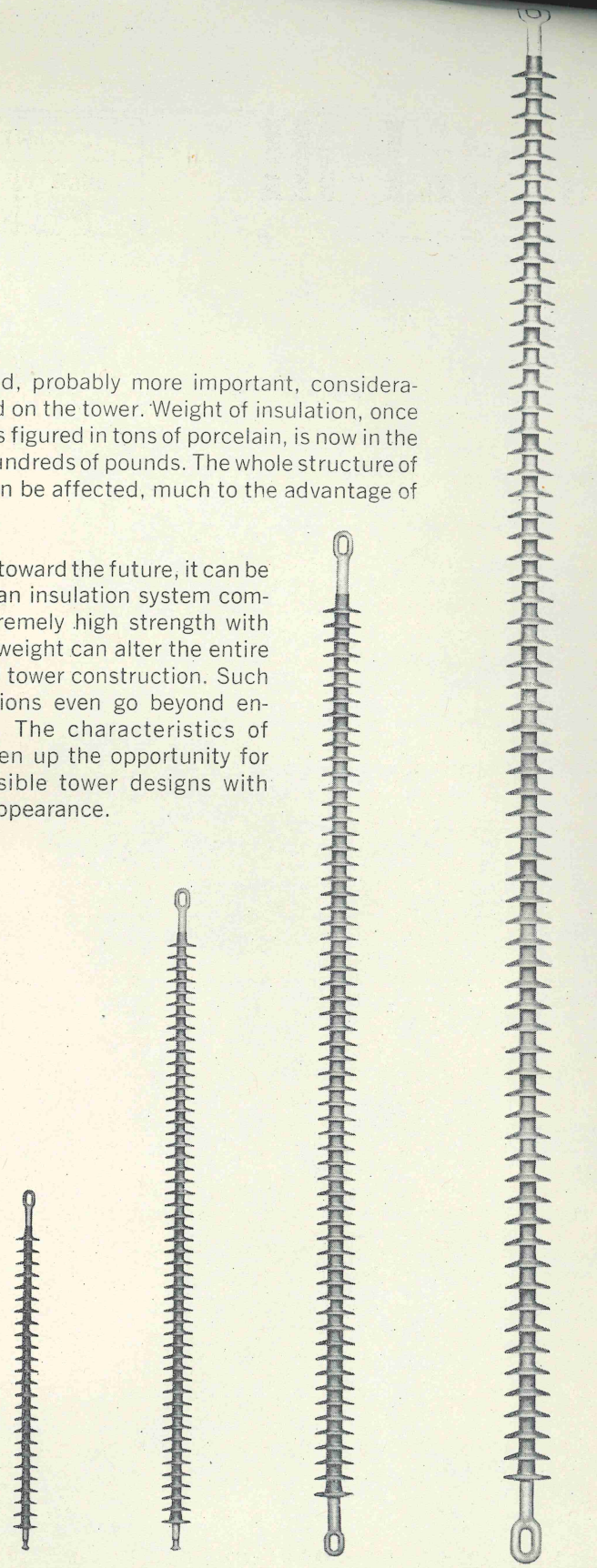
What do these figures tell us? First, construction savings. When you deal with less than one-tenth the weight of porcelain (often much less than one-tenth) many details of building a line are simplified. Hoisting methods and equipment, transportation and ground handling, and tower work are facilitated. Men experienced in the field will add many more details to the advantages of light weight.

A second, probably more important, consideration is load on the tower. Weight of insulation, once sometimes figured in tons of porcelain, is now in the order of hundreds of pounds. The whole structure of a tower can be affected, much to the advantage of the utility.

Looking toward the future, it can be seen that an insulation system combining extremely high strength with negligible weight can alter the entire concept of tower construction. Such considerations even go beyond engineering. The characteristics of Hi*Lite open up the opportunity for many possible tower designs with pleasing appearance.

LE 4

80 000-POUND WORKING STRENGTH				
Hi*Lite Suspension Insulators		Porcelain Suspension Insulators Four Strings Number 47614 40 000-Pound M&E Rating 5¾-Inch Section Length 17 Pounds Unit Weight Hardware Estimated 300 Pounds		Ratio of Weight — Hi*Lite To Porcelain
ction ength	Total Weight	Number Of Units Per String	Total Weight	
ches	Pounds		Pounds	Per Cent
90	61½	16	1388	4
110	72	19	1592	4
130	84	23	1864	4
150	96	26	2268	4
170	107	30	2540	4
232	145	40	3220	4
250	151	43	3424	4



10 000 LB. 20 000 LB. 40 000 LB. 80 000 LB.

Hi*LITE WORKING STRENGTHS

TABLE 1

10 000-POUND WORKING STRENGTH				
Hi*Lite Suspension Insulators		Porcelain Suspension Insulators One String Number 32440 20 000-Pound M&E Rating 5¾-Inch Section Length 11.9 Pounds Unit Weight		Ratio of Weight — Hi*Lite To Porcelain
Section Length	Total Weight	Number Of Units	Total Weight	
Inches	Pounds		Pounds	Per Cent
38¼	7	7	83	8
44	8½	8	95	8
52	9½	9	107	8
55	10	10	119	8
64	11½	11	131	8
74	13½	13	155	8
84	15	15	179	8
94	17	16	190	8
104	19	18	214	8
124	22½	22	262	8

Hi-Lite® insulators are c in their strength-to-weigh

In published material reference has been made to the light weight of Hi*Lite suspension insulators. Five to ten per cent the weight of porcelain equivalents has been a common expression. We have been asked to spell this out.

Tabular data presented here includes some latitude. Hi*Lite insulator strings are one-piece assemblies, having a fixed section length. Porcelain insulator strings consist of a series of 5¾-inch units. Therefore, the unit of measurement for total section length of a porcelain string is a multiple of 5¾ inches. This seldom divides evenly into the section length of a Hi*Lite string. Therefore, in making a comparison, one must round-off the number of units in a porcelain insulator string. This is the case when section length is used as a basis of comparison.

TABLE 2

20 000-POUND WORKING STRENGTH				
Hi*Lite Suspension Insulators		Porcelain Suspension Insulators One String Number 47614 40 000-Pound M&E Rating 5¾-Inch Section Length 17 Pounds Unit Weight		Ratio of Weight — Hi*Lite To Porcelain
Section Length	Total Weight	Number Of Units	Total Weight	
Inches	Pounds		Pounds	Per Cent
44⅜	11½	8	136	8
52⅜	13½	9	153	8
64⅜	16½	11	187	8
74⅜	18	13	221	8
84⅜	21¼	15	255	8
94⅜	24	16	272	8
104⅜	26¼	18	306	8
124⅜	31¼	22	374	8
144⅜	36¼	25	425	8
164⅜	41	29	493	8
226⅜	56¼	39	663	8

TABLE 3

40 000-POUND WORKING STRENGTH				
Hi*Lite Suspension Insulators		Porcelain Suspension Insulators Two Strings Number 47614 40 000-Pound M&E Rating 5¾-Inch Section Length 17 Pounds Unit Weight Hardware Estimated 100 Pounds		Ratio of Weight — Hi*Lite To Porcelain
Section Length	Total Weight	Number Of Units Per String	Total Weight	
Inches	Pounds		Pounds	Per Cent
87	34½	15	610	5
107	42	19	746	5
127	46½	22	848	5
147	56	26	984	5
167	63	29	1086	5
229	85	40	1460	5
247	91½	43	1562	5

NGK INSULATORS, LTD.
(Nippon Gaishi Kaisha, Ltd.)
MIZUHO, NAGOYA, JAPAN

RESIN INSULATOR

(Abstract of NGK Review No.27, Jan., 1969)

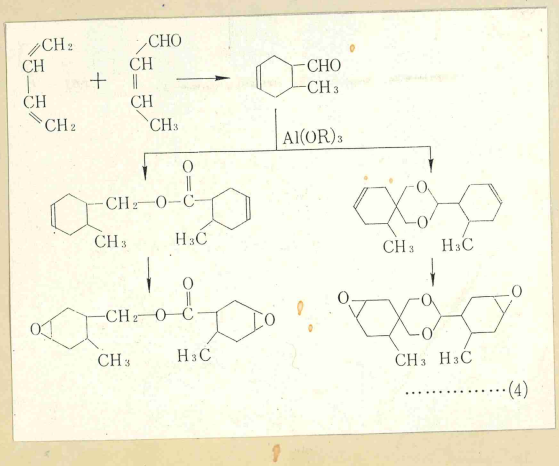
5. OUTDOOR RESIN INSULATORS

What has been said till now is all about indoor resin insulators which are made of bisphenol-type epoxy resin. This bisphenol-type epoxy resin contains in its structural formula benzene nucleus, because of which it lacks strength against tracking under outdoor polluted conditions.

It is reported that Outdoor Resin Insulators using a resin of this type have been put into trial service on transmission lines of some utilities in USA, but unfortunately within a year tracking occurred on the resin surface of some of these specimens.

Tracking is related to the "mobility" of electron and its characteristics vary according to the quantity of benzene nucleus and to the number of conjugate double bonds.

Our recent research revealed that for lack of benzene nucleus as shown in (4) formula, some formulation of cycloaliphatic type resin has excellent weatherability and anti-tracking characteristics, which make it feasible for outdoor use.



Further, when trihydrated alumina ($Al_2O_3 \cdot 3H_2O$) is used as a filler, this resin is thermally dissolved by arc, eliminating and gasifying isolated carbon within the resin and suppressing the occurrence of tracking on the resin surface. As a result of the trial production and experiment, some of the cycloaliphatic type resins showed favorable characteristics against Artificial Tracking Test and Field Test on seashore. The outline is reported as follows.

The physical properties of material of cast resin, obtained from test pieces are shown in Table 6.

Table 6. Physical Properties of Material of Cast Resin for Outdoor Use

Item	Specification applied	Unit	Measured values	Remarks
Dielectric strength	ASTM D149	V/mil	840	
Insulation resistance	ASTM D257	Ω	14×10^8 8.0×10^8	Normal After boiling
Resistivity	"	Ω - cm	$2.3 \sim 3.5 \times 10^{15}$	Volume resistivity
Dielectric constant	ASTM D150	-	4.3 4.0	50 c/s 1 Mc/s
Dielectric loss tangent	"	%	2.6×10^{-2} 1.0×10^{-2}	50 c/s 1 Mc/s
Resistibility against tracking	DIN 53480	mm	0.5	Depth of erosion after 700 drops
Hardness	Rockwell hardness	M scale	27	
Flexural strength	ASTM D790	psi	5,400	
Tensile strength	ASTM D638	"	6,600	
Elastic modulus	Strain gauge method	"	5.7×10^5	
Compressive strength	ASTM D695	"	14,500	
Flammability	ASTM D635-56T	-	Non-flammable	
Water absorption	ASTM D570	%	0.095	
Water absorption after boiling	"	%	0.35	
Specific gravity	ASTM D792	-	1.60	

Note: All values were obtained from test pieces.

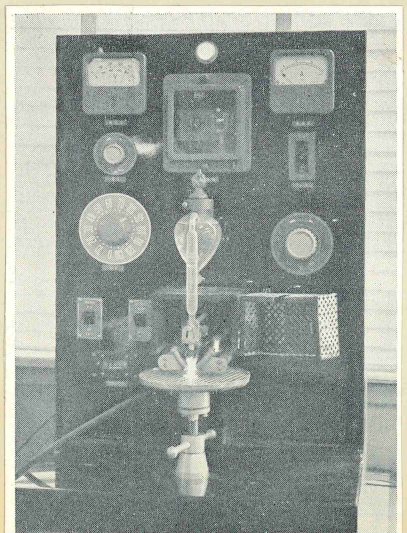
5.1 Tracking Test

Such tests as in DIN, IEC, JEC draft specifications, and Dust-Fog method have been released and standardized and found effective in evaluating anti-tracking performance of indoor use bisphenol-type resin. However it seems that this method is not so effective against resin insulator for outdoor, for which higher anti-tracking material is generally used and it is also very difficult to ascertain interrelation between these test results and the outdoor field performance.

Table 7 shows anti-tracking performances of indoor use bisphenol-type resin and of outdoor use cycloaliphatic-type resin obtained by KA Method of DIN 53480-1964, Fig. 10.

Table 7. Anti-Tracking Performances of Indoor Use Bisphenol-type Resin and of Outdoor Use Cycloaliphatic-type Resin (DIN 53480-1964)

Material of cast resin		Anti-Tracking Performance		
Type of resin	No.	Class	Number of drips up to formation of tracking	Depth of surface erosion, mm
Indoor use bisphenol-type resin	No.1	T 2	30	-
	2	T 2	28	-
	3	T 1	6	-
Outdoor use cycloaliphatic-type resin	No.1	E 3	100, no tracking	0.28
	2	E 3		0.28
	3	E 3		0.28
	4	E 3		0.26
	5	E 3		0.25
	6	E 3		0.26



The method used was to apply thickly a pollutant containing caolin and sodium chloride on the specimen insulator. After the pollutant had dried and adhered to the insulator, leakage current was forced to flow on the surface of the insulator for several hours continuously while water having the specific volume resistivity of more than 10,000 Ω-cm was sprayed at the rate of about 1 mm per minute.

By this method tracking can easily occur even on such organic insulating materials as can pass IEC method, fog flashover test or fog withstand test.

Tracking was not found on the NGK resin insulators for outdoor use even under such a severe artificial tracking test mentioned above.

In actual tests rod specimens the leakage distance of which was shortened as much as possible were used to permit an easy selection of materials needed.

First series of tests were made on clean specimens applying a highest test voltage not to produce flashover under spraying of water of 10,000 Ω-cm, the results of which are shown in Table (a). Specimens are of formulated cycloaliphatic resins of 45 mm diameter and 200 mm long. Measured leakage currents were 20 mA to 50mA at applied voltage of 20 kv to 25 kv. One out of six kinds of formulated resin showed tracking after 5 minutes testing as shown in Fig. 11. Remaining five kinds were intact.

Second series of test the results of which are in Table 8(b), were made on the remaining five specimens treated by caolin under the same procedure as for the first test series. No.4 and 5 specimens showed slight erosion after 30 minutes and 70 minutes respectively.

Above water spraying lakeage current test method is considered to have more room for improvement;however, it could distinguish anti-tracking performance more precisely than DIN method which could not produce any tracking on all of 6 kinds of specimens.

Table 8. Water Spraying Leakage Current Test on Various Materials for Outdoor Resin Insulator

(a) Spraying of water (10,000 Ω-cm) at precipitation of 1 mm/min for clean specimens

Material	Applied voltage	Leakage current	Duration of test	Results
No.1	20 kv to 25 kv	20 mA to 50 mA	180 min	no change
2			180	"
3			180	"
4			180	"
5			180	"
6			5	tracking

(b) Spraying of water (10,000 Ω-cm) at precipitation of 1 mm/min for specimens treated by caolin

Material	Applied voltage	Leakage current	Duration of test	Results
No.1	7 kv to 9 kv	20 mA to 30 mA	180 min	no change
2			180	"
3			180	"
4			30	slight errosion
5			70	"

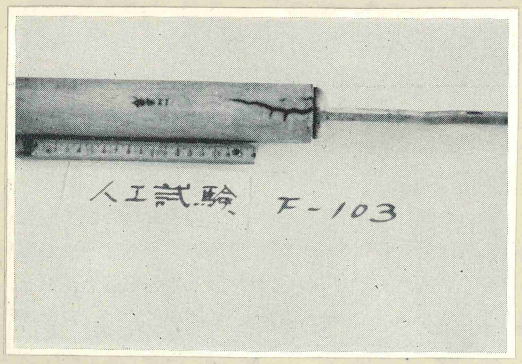


Fig.11. Tracking observed on No.6 specimen, cycloaliphatic epoxy resin, by water spraying leakage current test.

5.2 Outdoor Energized Field Test

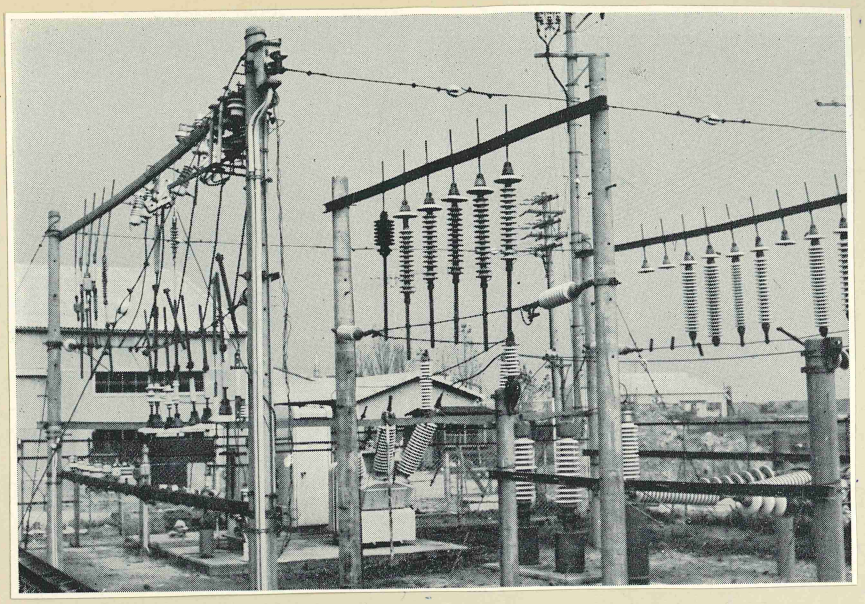
At present field tests are being done on many specimen insulators at NGK Chita Factory's field test stand under energizing which is located near the sea. Included among these are insulators whose leakage distance is extremely shortened by simulating severe pollution conditions. Three years have already passed and during that time leakage current as much as 10 mA was recorded many times. However, even under such conditions, neither tracking effect nor cracking were found for the insulators which passed water spraying leakage current test.

Table 9 shows outdoor field test results on proto type resin insulators. Fig. 12 shows outdoor test stand and tested insulators.

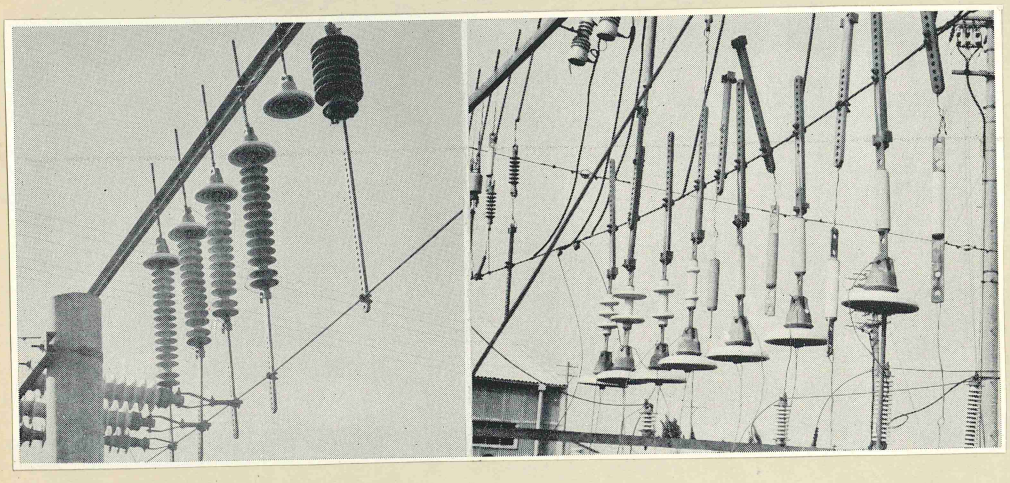
Table 9. Outdoor Field Test Results on Energized Outdoor Resin Insulators

Test specimens	Leakage distance ℓ (mm)	Applied voltage v (kv)	Arrangement of test specimens	ℓ/v	Units of specimens	Energized from	Results
25kv trolley line insulator	1,300 - 1,580	25	horizontal and vertical	52-63	7	Nov.'65	No change
20kv trolley line support insulator for tunnel	1,200	25	vertical	48	1	Nov.'66	"
Induction lighting insulator	500	6	"	83	1	Nov.'67	"
15kv strain insulator for distribution line	300*	6	"	50	4	Jan.'68	"
6kv strain insulator for distribution line, fog type	500	6	"	83	1	"	"
6kv pin insulator for distribution line, fog type	380	6	"	63	2	"	"

Note: * Test voltage 6kv is applied on shortened leakage distance 300 mm.



(a) Outdoor Energized Test Stand



(b) Trolley Line Insulator and Support Insulator for Tunnuel Use (applied voltage 25kv)

(c) Test Pieces of Various Resins (applied voltage 6kv)

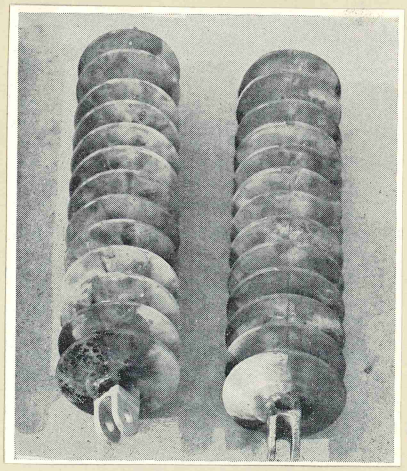
Fig. 12. Outdoor Energized Field Test on Various Resin Insulators

5.3 Arc Test

This is a method in which the condition of power arc flowing along the surface of insulator due to lightning, birds, etc. is assumed. After various conditions of current versus time were set up, this test was done by initiating arc by using fusible wire put on the the surface of the specimen insulator across the terminals. The power was supplied from a short circuit generator. The insulator withstood the arc severity of 4,000 A x 30 cycles without trunk separation and shed damage caused by local heat as found in ceramic insulator, or even the formation of carbonized layer as found on conventional bisphenol type epoxy resin.

Fig. 13 shows arc withstand test view of outdoor resin long-rod insulators and the specimens after the power arc test using 4,000A x 30 cycles.

(a) Power arc test
4,000 A x 30 cycles



(b) Resin insulators after power arc test, Insulators are traced by fuse wire vaporization

Fig. 13. Power Arc Test on Outdoor Use Resin Insulator

5.4 Accelerated Weathering Test

To confirm the weathering effect, 2,000 hours of weathering test which is equivalent to 10 years of weathering natural condition, was done on the test piece in accordance with ASTM E 42-64 method, but neither an extreme discoloring nor roughening of the surface were found. At the same time, there was no decrease in strength found even by accelerated deterioration caused by ultra-violet rays.

5.5 Proto type of Outdoor Use Resin Insulators

(1) Fig. 14 shows 25 kv trolley line resin insulator and Table 10 shows characteristics of it.

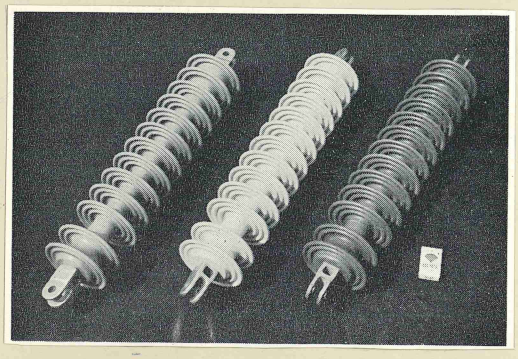


Fig. 14. 25kv trolley line resin insulator

Table 10. Characteristics of 25kv Trolley line insulator

Item	Test conditions	Results (observed value)
Leakage distance	-	1,580 mm
Number of shed	-	15
Weight	-	9 kg
Dry flashover voltage	JIS C 3801	280 kv
Wet flashover voltage	"	255 kv
50% impulse flashover voltage, positive	"	515 kv
negative	"	595 kv
Power arc test	4,000Ax30 Cycles	intact
Water spraying leakage current test	Special test	"
Refrigeration test	$-30^{\circ}C$ to $+30^{\circ}C$ 5 cycles	"
Tensile test	-	10 ton (hardware broken)

(2) Fig. 15 shows support insulator for tunnel use and Table 11 shows characteristics of it.

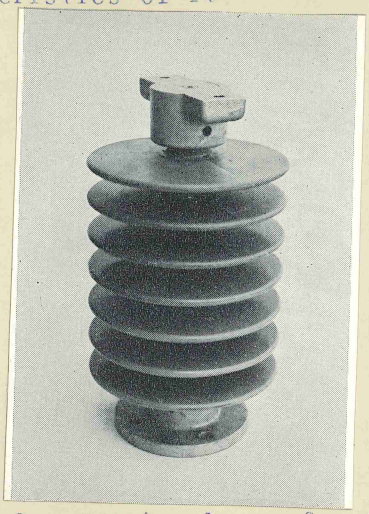


Fig. 15, Support insulator for tunnel use

Table 11, Characteristics of 20kv support insulator for tunnel use

Item	Test Condition	Results (observed value)
Leakage distance	-	1,200 mm
Number of shed	-	7
Weight	-	12.9 kg
Dry flashover voltage	JIS C3801	135 kv
Wet flashover voltage	"	120 kv
50% impulse voltage, pos.	"	230 kv
Water spraying leakage current test	Special test	intact
Refrigeration test	$-40^{\circ}C$ to $-30^{\circ}C$ 5 cycles	"
Temperature cycle test	JIS C 3801 $90^{\circ}C$ 5 cycles	"
Bending test	-	600 kg
Bending fatigue test	max 120 kg to min 80 kg 10^6 cycles	intact
Energized field test	25kv 2 years	"

(3) Insulated transmission tower member

Fig.16 shows FRP arm for transmission tower. Advantages of it are realized as for minimum right of way, unbalanced insulation, bird guard, etc.

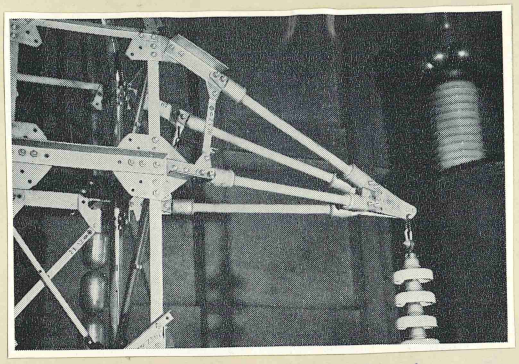


Fig. 16. FRP arm for transmission tower

Fig. 17 shows the FRP specimen insulator for transmission tower member use, of which the good results were shown at arc test of 40 kA, 6 cycles. Other kinds of simulated test on distribution insulating arms are being carried out at present.

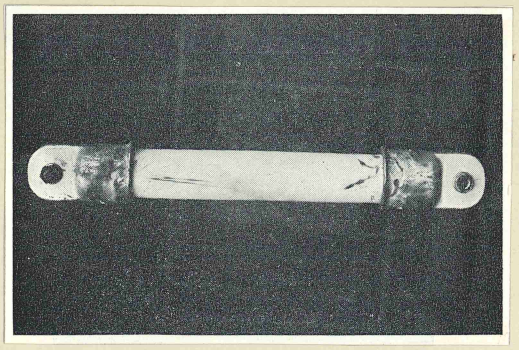


Fig. 17. FRP specimen insulator for transmission tower member

(4) Strain insulator for trolley line

Fig. 18 shows strain insulator for trolley line. This insulator has been used in actual line for 5 years.

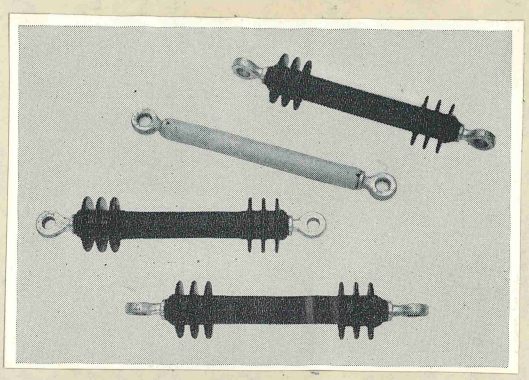


Fig. 18. Strain insulator for trolley line

(5) Induction lighting insulator

Insulator for induction lighting of transmission line in trial use for 66 kv line.

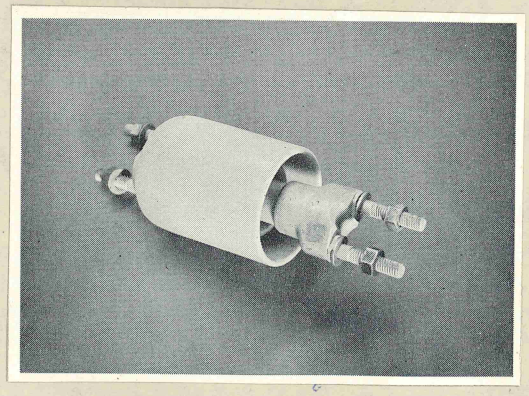


Fig. 19. Insulator for induction lighting

(6) Section insulator for trolley line

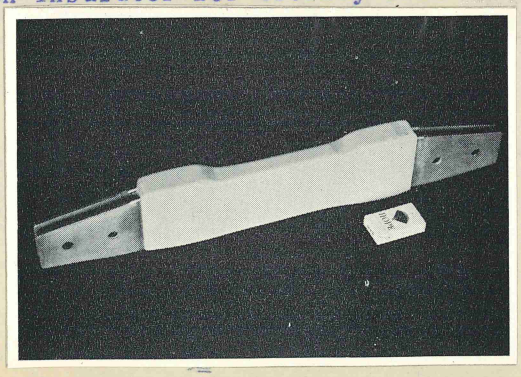
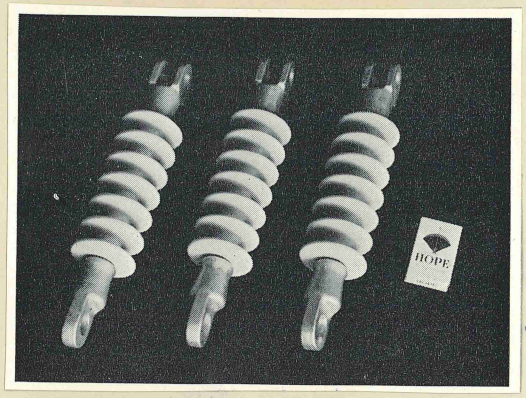


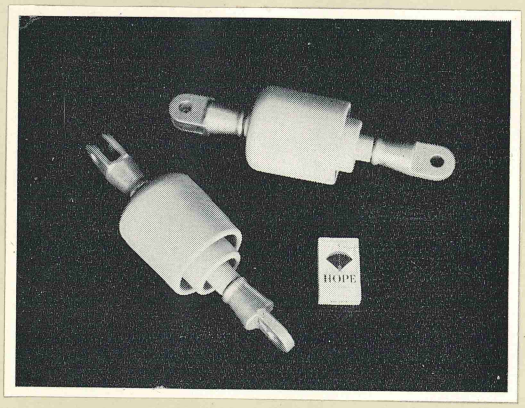
Fig. 20. Section insulator for trolley line

(7) Distribution line insulators

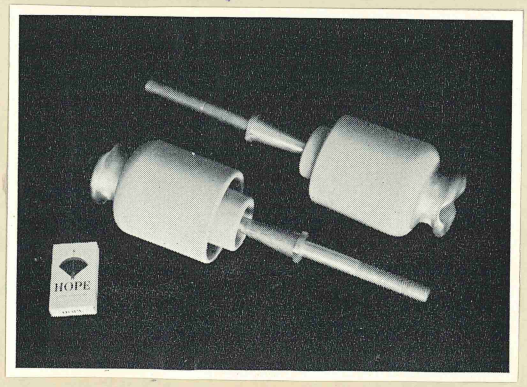
Proto type insulator of 15 kv and 6 kv strain type and 6 kv pin type have been developed. They showed superior performance at various tests and have been in trial use at 6 kv distribution line at NGK high voltage laboratory.



(a) 15 kv strain insulator



(b) 6 kv strain insulator
(fog type)



(c) 6 kv pin type insulator
(fog type)

Fig. 21. Distribution line insulator

6. CONCLUDING REMARKS

Cycloaliphatic expoxy resin has excellent tracking characteristics and some of its formation derivatives indicate the possibility of application to outdoor use for its high shock-resistant, weathering and tracking performances. However, before its application to practical and wide use, further extensive field tests regarding its weatherability as well as studies on the range of application is considered imperative.

NGK INSULATORS, LTD.
MIZUHO, NAGOYA, JAPAN

April 26, 1974

To: LOCKE INSULATORS, INC.

MEMORANDUM

Sub.: Anti-tracking property of silicone insulators

It is reported in the brochure from the manufacturer that a RODURFLEX-insulator composed of a FRP core and silicone rubber sheds has good anti-contamination performance because of its water-repellency, slenderness and long surface creepage distance. We have no firsthand information nor test data in our laboratory to evaluate these claims by the manufacturer.

In relation with the anti-contamination performance, tracking resistivity is also very important particularly for outdoor insulators made of synthetic materials especially when they are used under severely contaminated environment. According to our test results, tracking resistivity of silicone rubber was inferior to that of cycloaliphatic epoxy resin and polytetrafluorethylene (P.T.F.E). Refer to Technical Note TN-74012 attached.

At the present moment, NGK is forcussing our development efforts on cycloaliphatic epoxy reisn insulators and P.T.F.E. insulators though silicone rubber remains one of our objects of research and development.

NGK INSULATORS, LTD.
MIZUHO, NAGOYA, JAPAN

Tecknical Note No.TN-74012
April 15, 1974

TRACKING RESISTIVITY OF SILICONE RUBBER

Drafted by K. Taketani

TN-74012

1. Introduction

Tracking resistivity is one of the most important performances of synthetic materials for outdoor insulation. For evaluating the tracking resistivity of representative synthetic materials including silicone rubber, NGK conducted artificial tracking test on them in a comparative manner. This technical note covers the test results and our comments on the tracking resistivity of silicone rubber.

2. Test Samples

Test samples are listed in Table 1. As shown in Fig. 1, a test piece is so shaped that tracking may take place at the narrow part of the test piece and that the effect of the electrode may be eliminated.

Table 1 Test samples

Item No.	Material	No. of samples	Remarks
(1)	Silicone rubber-A	4	vulcanized at room temperature
(2)	Silicone rubber-B	3	- ditto -
(3)	Silicone rubber-C	3	vulcanized at high temperature
(4)	Cycloaliphatic epoxy resin	4	manufactured by NGK
(5)	Polytetrafluorethylene (P.T.F.E.)	4	introduced from Rebosio Industris Elettrotechnica, S.p.A.

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TN-74012 Drafted by K. Taketani

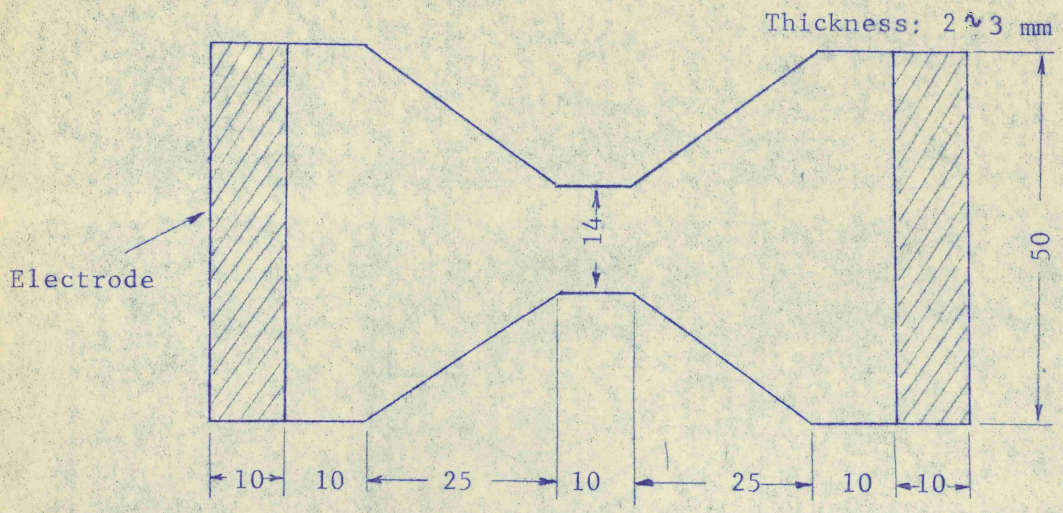

Fig. 1 Test piece

3. Test Method

The top surface of each test piece was uniformly contaminated with a mixture of Tonoko (insoluble substance used in artificial contamination test) and water by using a suitable brush and then completely dried. The thickness of the contaminant layer was from 0.3 to 1.0 mm. The test pieces of one each were brought into a sealed fog chamber and set in a line on a insulated stand (see Fig. 2). A test voltage just below the flashover voltage was simultaneously applied on the test pieces and artificial fog (water resistivity: approx. 17,000 Ω-cm, precipitation rate: approx. 0.025 mm/min.) was produced by two spray nozzles preventing direct spray over the test pieces. Leakage current flowing on the surface of each test piece was recorded by a ink writing oscillograph. The applied voltage and fog were kept constant until any signs of tracking was observed on any test pieces. After each test the surfaces of all test pieces were carefully observed.

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Drafted by K. Taketani
TN-74012

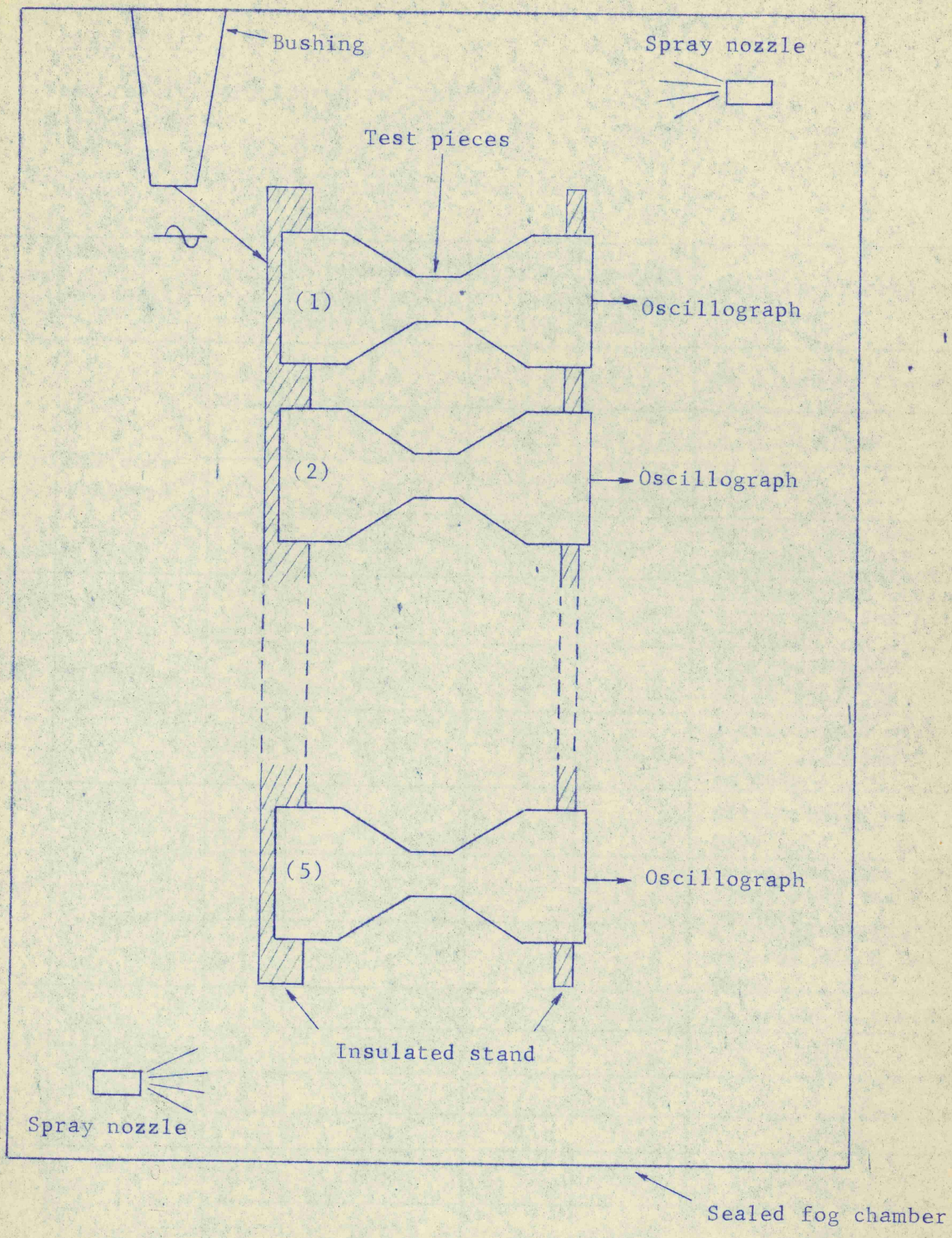

Fig. 2 Test arrangement

NGK—27 A—4 300 48.1 S

TN-74012 Drafted by K. Taketani

4. Test Results

Test results are listed in Table 2.

Table 2 Test results

Item No.	Material	Test No.	Thickness of contamination layer (mm)	Applied voltage (kV)	Leakage current (mA)	Results of observation
(1)	Silicone rubber-A	1	0.3	7	5.5	No signs of tracking
		2	0.6	7	11.0	- ditto -
		3	0.6	7	13.8	- ditto -
		4	1.0	7	13.8	Slight deterioration perceptible with carefull observation
(2)	Silicone rubber-B	1	0.3	7	5.5	A carboinzed stripe, 0.5mm wide and 0.15 mm deep
		2	0.6	7	11.0	Few carbonized stripes, 0.7mm wide and 0.2mm deep
		3	0.6	7	16.8	A carbonized stripe, 0.5mm wide and 0.2 mm deep
(3)	Silicone rubber-C	1	0.3	7	9.7	Slight deterioration
		2	0.6	7	13.8	Few eroded stripes, 1.0mm wide and 0.3 mm deep
		3	0.6	7	22.0	A eroded stripe, 0.3 mm wide and 0.1mm deep
(4)	Cyclo-aliphatic epoxy resin	1	0.3	7	9.7	No signs of tracking
		2	0.6	7	13.8	- ditto -
		3	0.6	7	11.0	- ditto -
		4	1.0	7	19.3	- ditto -
(5)	P.T.F.E.	1	0.3	7	5.3	- ditto -
		2	0.6	7	14.6	- ditto -
		3	0.6	7	11.0	- ditto -
		4	1.0	7	22.0	- ditto -

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Drafted by K. Taketani

5. Comments

According to our test results listed in Table 2, tracking resistivity of silicone rubber is inferior to that of cycloaliphatic epoxy resin and P.T.F.E. Although the ultimate evaluation of silicon rubber depends on the kind of the materials used, as far as materials available to us are concerned, it is rather difficult to obtain with silicone rubber such tracking resistivity as applicable to the Japanese severe contamination conditions.

82-27 A-4 300 48.1 S

FORSCHUNGS-
GEMEINSCHAFT FÜR
HOCHSPANNUNGS- UND HOCHSTROMTECHNIK E.V.

Highest leakage current impulse as criterion for the insulation performance of polluted insulators

M. P. Verma [+]

Pollution conditions are more or less inherent for outdoor insulation and lead to the development of conductivity on the surface of an insulator. This gives rise to thermal processes resulting into discharges which reduce the insulation strength. The insulation strength can be reduced to such an extent that a pollution flashover at the line-to-ground voltage becomes feasible. Fig. 1 shows a pollution flashover of an insulator.

To estimate the insulation strength of insulators under pollution in service, usually the limiting characteristic "Flashover voltage as a function of the degree of pollution" is determined in the laboratory (Fig. 2). The degree of pollution is expressed, according to the test procedure applied , in g/l for the case of salt fog test, in surface conductivity uS for the case of solid layer test procedure and in specific deposit mg/cm^2 for the japanese procedure. These values represent, however, the static degree of pollution (without test voltage). The dynamic value of the degree of pollution occuring during a pollution test can not be directly determined. The relation between the static and the dynamic values of the degree of pollution depends on the procedure used. Hence, the characteristics differ from each other correspondingly. These differences have led to many thoughts and discussions on the suitability and the correspondence of the existing test procedures with respect to the various natural pollution conditions.

[+] Dr.-Ing. M. P. Verma is Head of the Insulator Department of the Forschungsgemeinschaft für Hochspannungs- und Hochstromtechnik e. V., Mannheim-Rheinau.

This investigation presents a fundamental criterion for the insulation behaviour of polluted insulators, which is suitable to bring more clearness to the mechanism of a pollution flashover and the different types of pollution test procedures to a new common basis. With this, partly expensive and controversial test procedures and their reasoning seem to become unnecessary.

Highest leakage current impulse as the new criterion

The oscillograms recorded during the determination of the limiting characteristic of Fig. 2 show that a flashover occuring at a given voltage and the corresponding degree of pollution is always accompanied by a current impulse of definite amplitude. The impulse is the highest one among the many impulses during a test and occurs in case of tests ending with flashover in the last half-cycle before the flashover (Fig. 3 a). In the following, this critical impulse is indicated by $\hat{I}_{max.c}$ and is to be understood as the peak value of the highest current impulse. For every type of insulator the minimum value (considering the scattering of values) of $\hat{I}_{max.c}$ is characteristic for the pollution flashover at a definite voltage. If $\hat{I}_{max.c}$ is determined with flashover tests at various voltages and corresponding degrees of pollution acc. to Fig. 2, the insulation behaviour of an insulator under pollution can be represented by a new characteristic (Fig. 4). $\hat{I}_{max.c}$ is independent of the method, how the conductivity is created on the surface and is given by the residual resistance of the unoverbridged part of an insulator in series with the arc (Fig. 5).

If the degree of pollution applied is not sufficiently high for a particular voltage, no flashover occurs in the pollution test. During the whole test duration many impulses of different amplitudes occur. The highest impulse $\hat{I}_{max}$ amongst these is in this case a measure for the dynamic degree of pollution reached on the insulator surface during the test duration, whereas $\hat{I}_{max.c}$ is the value of impulse necessary for the insulator to flashover at the particular voltage.

The values of $\hat{I}_{max}$ and $\hat{I}_{max.c}$ result out of the transient phenomena which occur on account of the applied voltage and the dynamic developing conductivity on the insulator surface.

$U_{ü}$-$\hat{I}_{max.c}$-characteristic for the longrod insulator L 75/27-150

Fig. 6 shows as an example the characteristic for the 27-sheded longrod insulator. For the reason of simplicity the modified "flow-on" procedure was used to determine the characteristic. After the application of pollution with a suspension of Aerosil, Photo-Flo and salt, the statical surface conductivity was determined. The insulator was allowed to dry up completely and then wetted with steam under constant voltage. Each test lasted until flashover or at most for half an hour. The statical surface conductivity was varied from test to test in small steps so that at every voltage level the flashover occurred at the smallest necessary surface conductivity. The value of $\hat{I}_{max.c}$ in the half-cycle before flashover was measured. Out of several tests at one voltage the minimum value of $\hat{I}_{max.c}$ was determined and attached to this voltage.

The characteristic in Fig. 6 means that e. g. at the line-to-ground voltage of 72 kV a pollution flashover on this insulator can occur only when at least the corresponding value of $\hat{I}_{max.c}$ occurs.

Silicon-rubber Insulator

Let us now try to analyse the expected performance of silicon-rubber insulators under pollution in view of the new criterion of $\hat{I}_{max.c}$. The characteristic features of the silicon-rubber insulator are the thin core and the water repelling property of the material. In order to examine the effects of these features separately three insulators (Fig. 7) -two porcelain of different core diameters and one silicon-rubber of same dimensions as those of thinner porcelain- have been tested in horizontal position with the salt-fog

test procedure. Fig. 8 shows the flashover characteristic of the two porcelain insulators having the core diameter of 25 mm and 75 mm respectively, other dimensions remaining constant. It can be clearly seen that the insulator 1 with the thinner core needs at a voltage of 23 kV a higher current $\hat{I}_{max.c}$ and therefore a higher degree of pollution (3,5 g/l) to flashover than the insulator 2 with the thicker core. This is how the better performance of the thinner core can be understood.

If the insulator 3, which is made of silicon-rubber and has the same dimensions as of the insulator 1 made of porcelain, is subjected to the salt-fog with the same salinity of 3,5 g/l, i , e , to the same static degree of pollution at the same voltage of 23 kV, no flashover occurs. The highest value of $\hat{I}_{max}$ reached during the test period of one hour is only 75 mA, which is much lower than the critical value $\hat{I}_{max.c}$ of 445 mA (Insulator 1), necessary for the insulators of this shape to flashover at a voltage of 23 kV. For the same static degree of pollution of 3,5 g/l and at the same voltage of 23 kV, insulator 1 of porcelain leads to flashover giving the value $\hat{I}_{max.c}$ of 445 mA whereas insulator 2 of silicon-rubber does not flashover and gives $\hat{I}_{max}$ of only 75 mA. This result can be attributed to the water repelling property of silicon-rubber because of which the dynamic degree of pollution reached on the surface of silicon-rubber insulator for the same static degree of pollution applied remains much below than in the case of porcelain insulator of the same shape.

Plastic insulators in general must, however, withstand the natural conditions without any appreciable deterioration of the material. A 110 kV silicon-rubber insulator has been subjected to natural pollution conditions in our outdoor testing station near Mannheim at a test voltage of 125 kV for about two years. After this period the insulator with natural deposits was wetted artificially at the line-to-ground voltage

of 72 kV. No flashover occurred and the highest leakage current which could be reached was only 30 mA. This being a low value, confirmed the visual observation that a continuous conductive layer could not be formed on the surface of the insulator because of the still existing water repelling property of silicon-rubber.

Tests under natural conditions will be continued further in order to conclude on the long-term behaviour of the silicon-rubber, which has been satisfactory so far.

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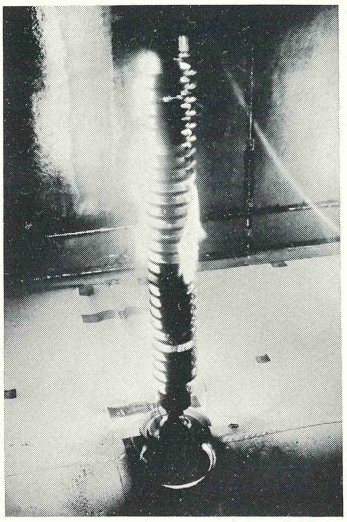

Fig. 1

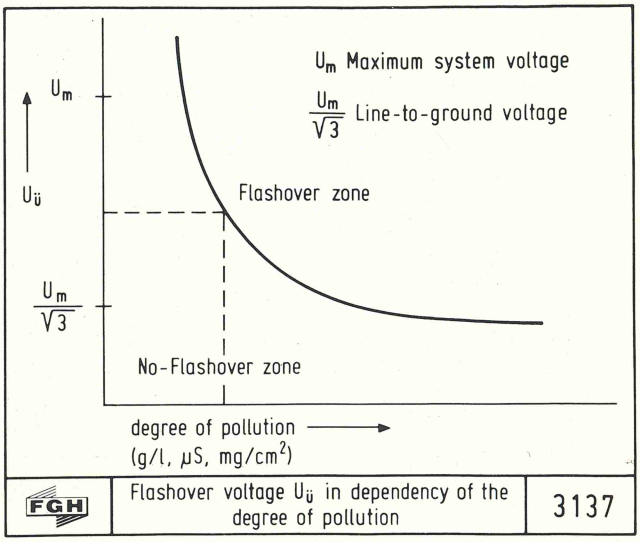

Fig. 2

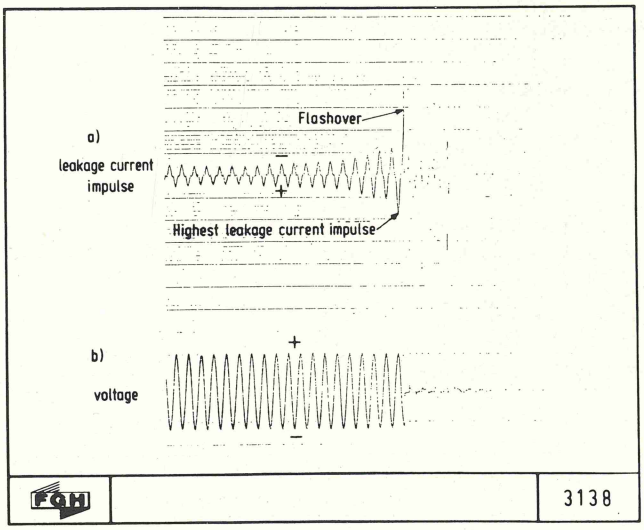

Fig. 3

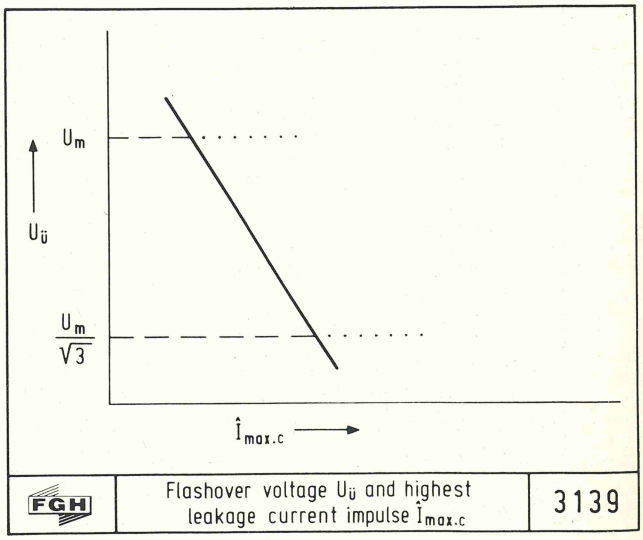

Fig. 4

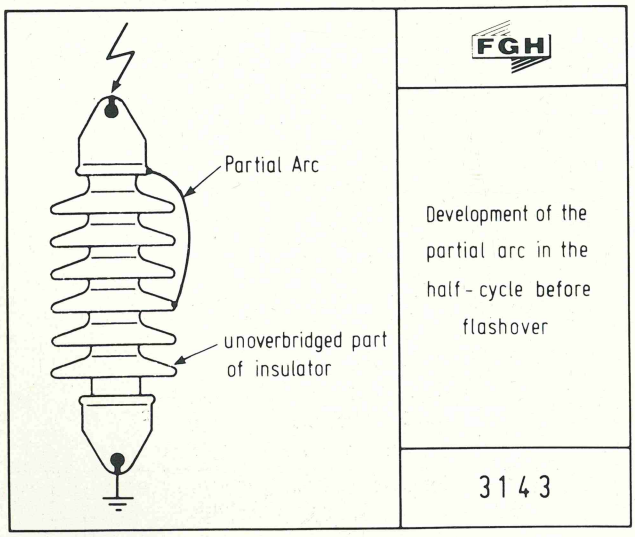

Fig. 5

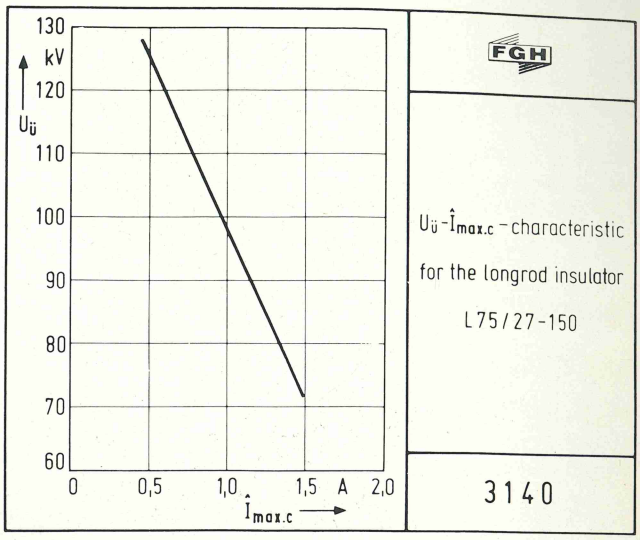

Fig. 6

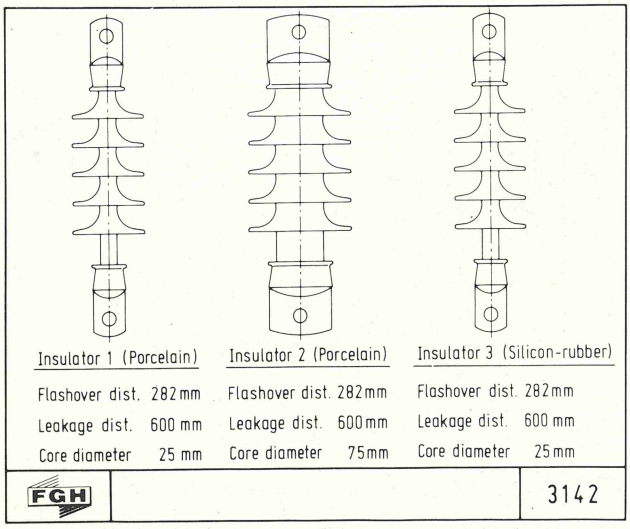

Fig. 7

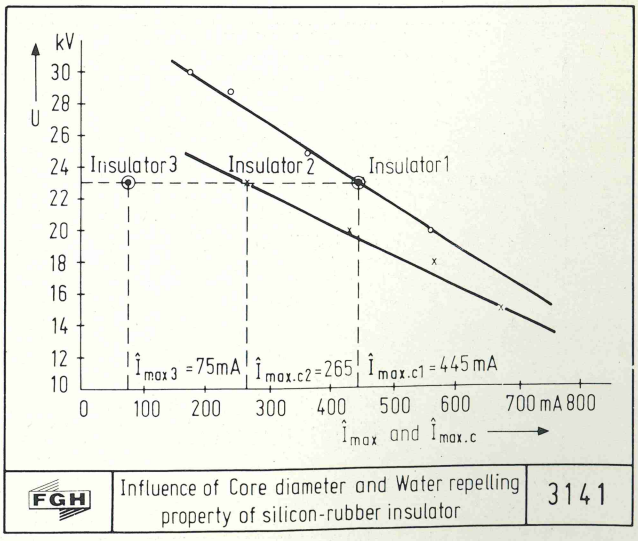

Fig. 8

FORSCHUNGS-
GEMEINSCHAFT FÜR
HOCHSPANNUNGS- UND HOCHSTROMTECHNIK E. V.
MANNHEIM-RHEINAU

FACHBEREICH 1
– Drehstromtechnik –

Composite Longrod Insulators for Transmission Lines

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Forschungsgemeinschaft für Hochspannungs- und Hochstromtechnik e. V.
Mannheim, Germany

Paper for
IEEE WG, Winter Power Meeting, New York 1977

Introduction

A composite longrod insulator offers many advantages as compared with the conventional porcelain longrod and porcelain and glass cap-and-pin insulators /1/. The composite longrod insulator, however, also presents new problems leading finally to the question of life-time of insulators in service. A few types have been developed using different constructional details and synthetic materials covering a glass-fibre resin rod, the latter being in common to all types /2/. Before the question of regular use of these insulators in transmission lines is decided, the laboratory tests must be defined and specified. From the point of view of such an insulator, the tests should cover the materials used and also the final insulator with specific reference to its construction. With respect to the stresses experienced by the insulators in service, some of these can be very different depending on the climatic and environmental conditions of the site or the country of use. The following view points must therefore be kept in mind while dealing with the question of test specifications.

1. A realistic and differential survey of the stresses in service is necessary, so that the demands on the performance of insulators also remain realistic.

2. The test specifications should not be suited to the insulators already developed but should cover as far as possible the actual service conditions faced by the insulators. The question of relevance is therefore very important.

3. A clear distinction between different effects caused sometimes by the same phenomenon must be made so that proper solutions to problems are conceived.

The problems involved with the composite insulator are well known. Several concepts on tests to be performed are also present. The aim of this paper is to show only the testing and investigation activities of the FGH in this field. The results and the conclusions are presented.

Surface conductivity and electrical discharges - their effects on the composite insulator

Among many mechanical, electrical and thermal stresses to be faced by the composite insulator in service, the one is the rise of conductivity due to pollution on the insulator surface. This results into the flow of a current along the leakage path and electrical discharges preferably at sections of high current density. This phenomenon has two different effects. In one case the discharges can develope into a partial arc leading to the pollution flashover at service voltage without having necessarily caused any pre-damage to the insulator. The effect of reduction of insulation strength applies here in the same way as in case of ceramic insulators. The insulator strength is restored as soon as pollution and wetting conditions disappear.

The other effect of leakage current and electrical discharges is finally the damage of the synthetic material, may be by tracking, erosion etc. The protection role of the external material for the glass-fibre rod is lost and the damage may extend to the interface and finally to the rod. The insulation strength of the insulator is permanently reduced or lost.

The second effect raises the question of life-time of the composite insulator and plays a vital role as far as the regular use of such insulators in transmission line is concerned.

Field Test

The FGH started investigations of the effects of leakage current and electrical discharges on composite insulators under natural conditions at the Friesenheimer Island some 8 years ago. Different composite insulators and chains for 220-kV-systems were exposed to natural conditions at the permanent line-to-ground voltage. Discharge currents were recorded in 4 levels with the help of counters. The Figure below shows as an example the record on a particular insulator-chain during the years of investigations.

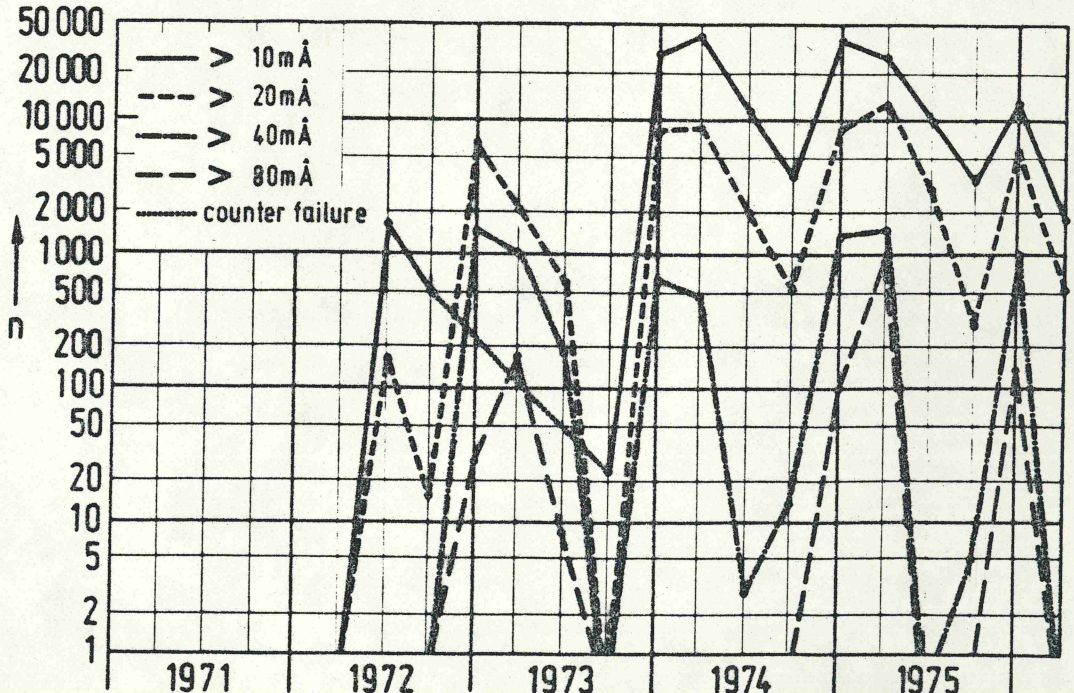

Fig. 1

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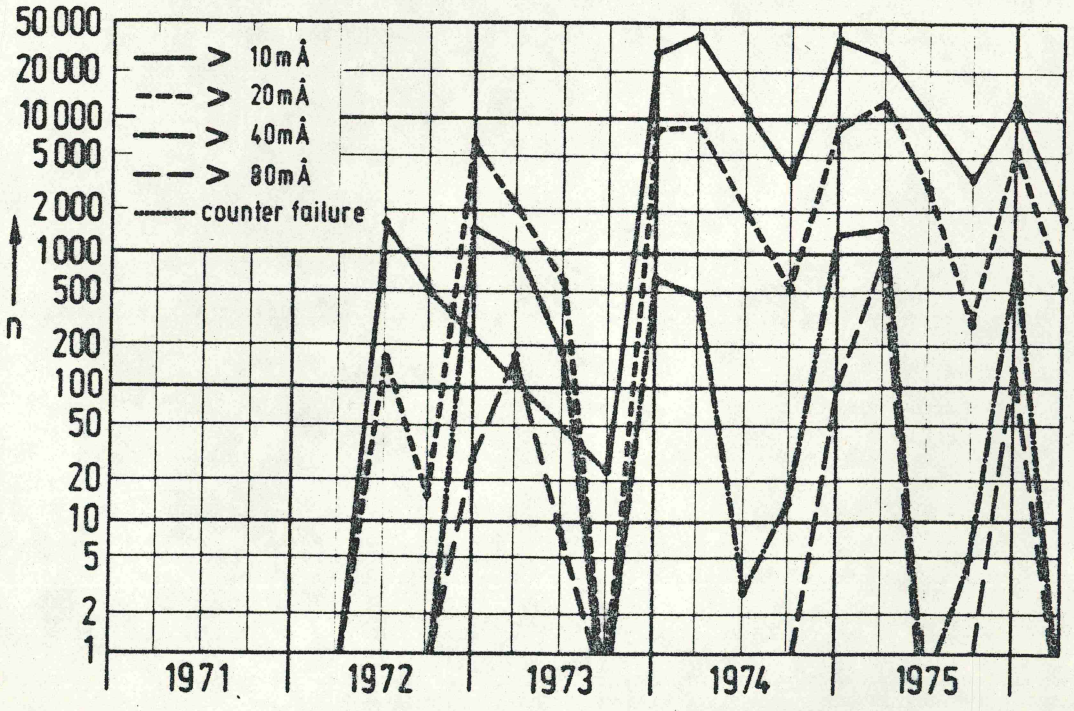

Fig. 1

After about 5 years the bottom insulator in the chain failed at the hot end. The damage caused can be seen in Fig. 2

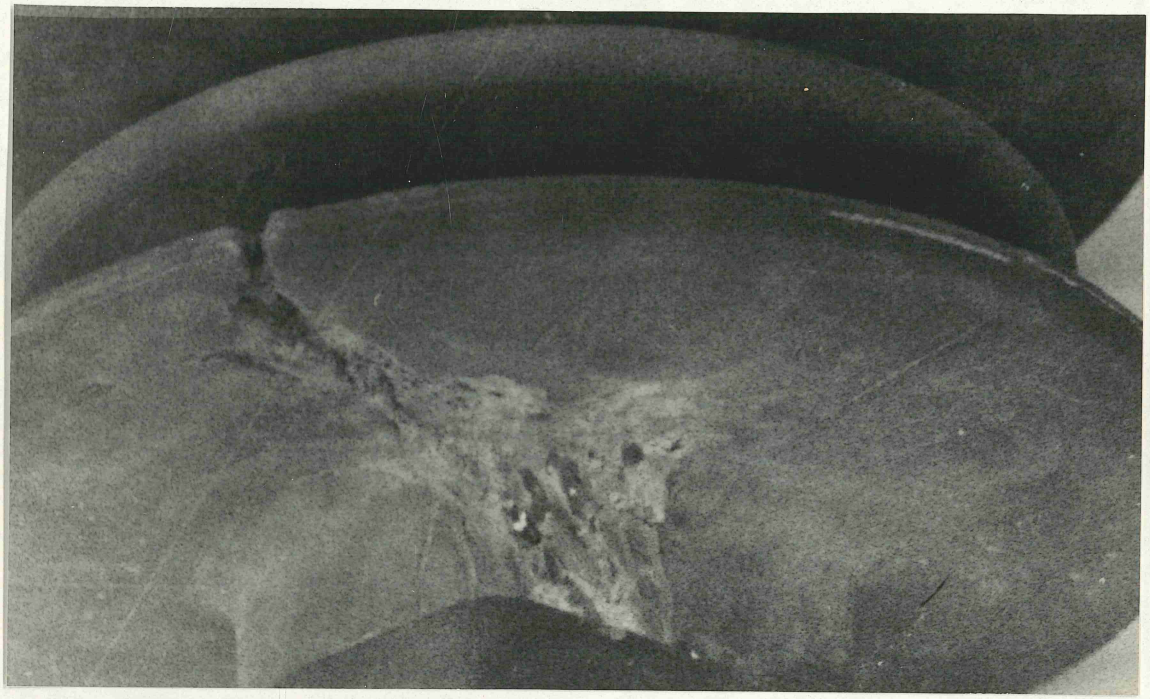

Fig. 2

Fig. 3 shows the record of leakage current pulses on a 220-kV-chain of another insulator type.

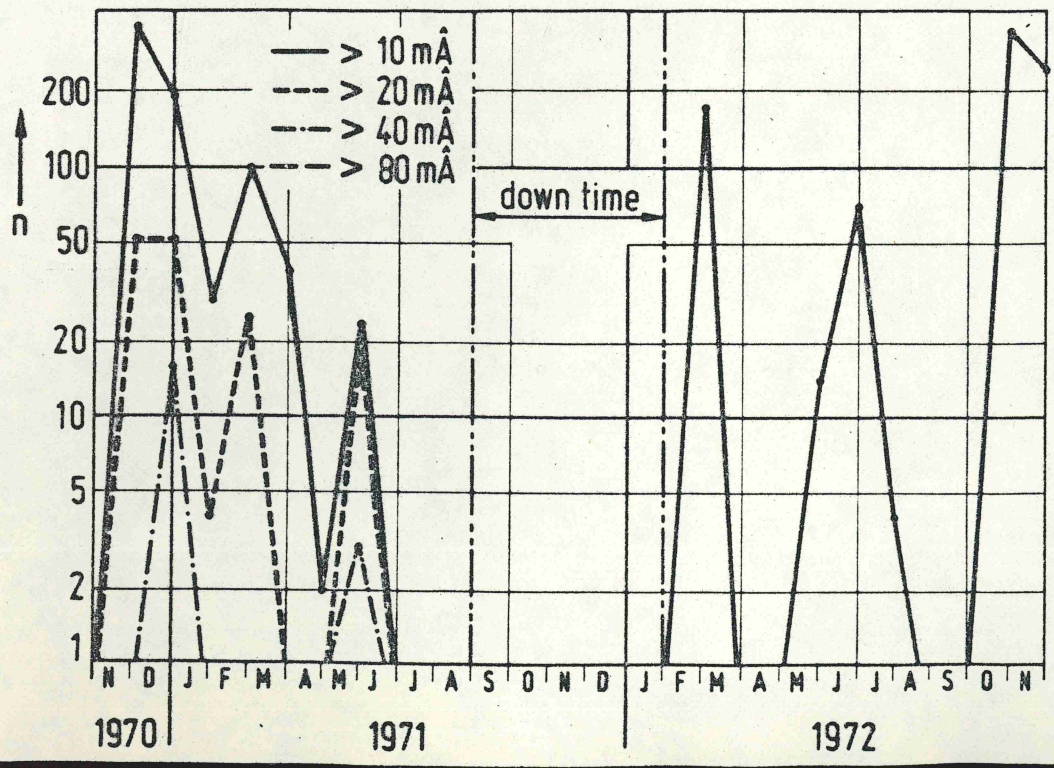

Fig. 3

After a relatively short time puncture of a few sheds in the vicinity of the core was detected.

Conclusions

1. The field test enables determination of performance of different insulators on comparative basis and is useful to sort out unsuitable composite insulators. Analysis of failures helps further development. It is natural that the duration of the field test for good insulators will have to be long. No unrealistic measures should be adopted to shorten the test duration. E. g. no higher test voltage than the service voltage ($U_m/\sqrt{3}$) is permissible.

2. The frequency of smaller leakage current pulses is higher than that of bigger ones because the degree of pollution necessary for them occurs more frequently. Smaller current pulses in a large number are more significant than a few bigger ones with respect to the stress caused to the insulator.

3. The flow of leakage current on the insulator surface causes two types of stress, the one being at the roots of discharges.

   The other stress occurs in channels due to concentration of the leakage current. The flow of leakage current uniformly on the whole surface could be much less critical for the insulator.

Laboratory Test

Fog Chamber Test

A fog chamber test has been developed and practiced at the FGH since 8 years, in which composite insulators reduced proportionally in length for 20 kV are exposed permanently to salt fog at the test

voltage of $24/\sqrt{3}$ kV. The fog is generated in the chamber by means of a room humidifier, the rate of flow of water being 0,4 l/h/m³ of the chamber. Acc. to the experience gained, the salinity of water for fog generation has been fixed to 10 g/l. The test continues for 1000 hours. The criterion for passing the test is no tracking and no erosion after the test duration.

Fig. 4 shows as an example tracking occurred on a 20-kV-post-insulator which did not pass the test.

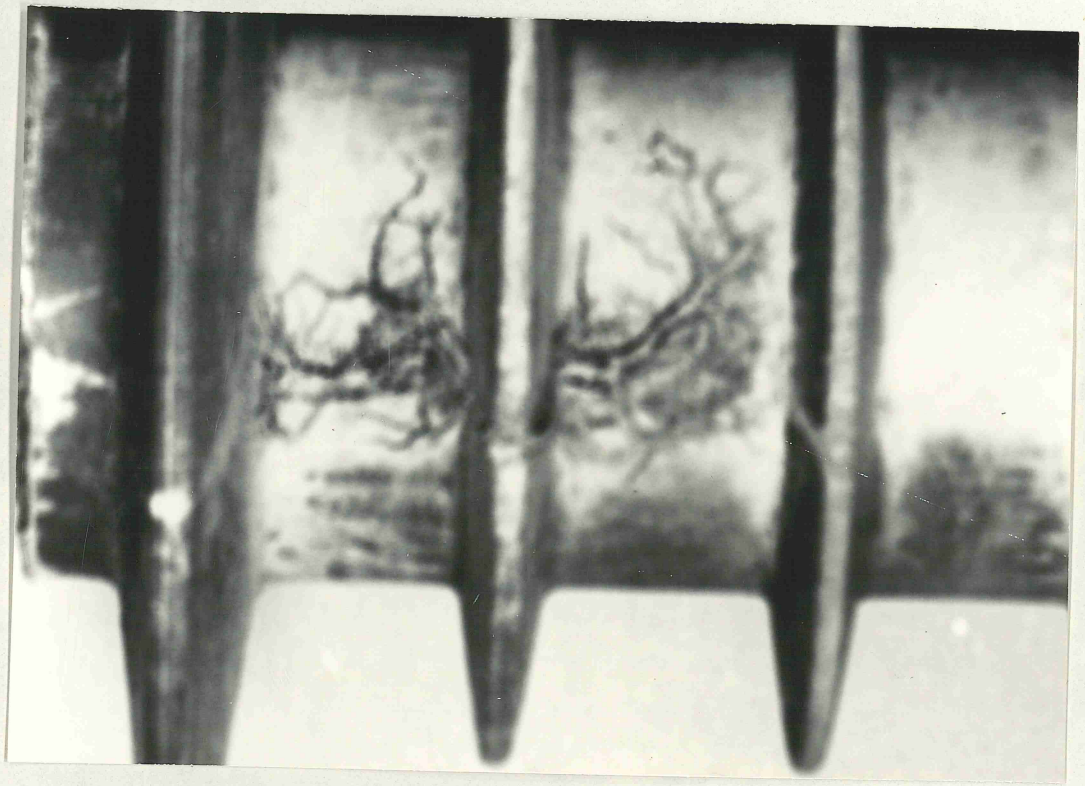

Fig. 4

The validity of the results is continuously checked with service experiences and the results of the field test. Insulators which have passed this test have also withstood service conditions so far. Failures of those insulators in service are also known which did not withstand the test. The basic principles of the test are as follows:

1. No higher voltage stress than that in service is applied.

2. Under the continuous ambient conditions (humidity oversaturation by 25 % and conductive fog corresponding to 10 g/l of NaCl-solution) the electrical discharges occur in the beginning of the test at random at places of high current density. This corresponds to phenomena in service.

3. The insulator is stressed with partial arcs as well as with the flow of the leakage current on parts of the leakage path. The discharges also cause UV-rays, so that the test does include stresses due to UV-rays although their intensity is not measured yet.

4. The test is conceived to sort out unsuitable insulators of insufficient resistance to tracking and erosion. Life-time prediction is not possible.

Pollution Test of Composite Insulators

In different laboratories somewhat extensive pollution tests have been performed on the composite insulators, whereby the aim of a pollution test on a composite insulator doesn't seem to be clear. In our opinion the aim of a pollution test on a composite insulator can not be anything else or more than in case of ceramic insulators, i. e. to determine the insulation strength under pollution. This is true even if the one or the other composite insulator shows tracking,

erosion and other damages during the pollution test. Good insulators experiencing no damage show in general better insulation performance under pollution than the corresponding (same shape and leakage path) ceramic or glass insulators. This is often due to the water repelling property of the synthetic material. The FGH is of the opinion that the salt-fog test alone would be sufficient for composite insulators. This procedure is specially useful to check the water repelling property which is significant for the performance also in service. As far as insulation performance under industry-pollution is concerned, sufficient knowledge and experience already gathered on ceramic and glass insulators enable complete assessment of composite insulators.

Use of Composite Longrod Insulators in Germany

Experiences on composite longrod insulators from field and laboratory tests and trial in transmission lines have been gained since about 10 years. Out of the tested insulators made of teflon, cycloaliphatic resin and silicon rubber, the last one has shown so far the best performance. The utilities have now started using silicon rubber composite longrod insulators in transmission lines. A case of frequent application for this type of insulator is given when an existing 220-kV-line is uprated to 380 kV. The composite insulator offers in such cases the big advantage of the shortest length as compared to those of the ceramic and glass insulators. The silicon rubber insulator is characterized by a very good water repelling property which is not only responsible for a good insulation performance under pollution but also contributes significantly to the long-time performance of the insulator.

References

/1/ E. Abilgaard, E. Bauer and K. L. de Lussanet de la Sablonière: Composite long-rod insulators and their influence on the design of overhead lines. CIGRE Report 22-03 (1976)

/2/ G. Karady, N. Souchereau and R. Vinet: New test methods for synthetic insulators. CIGRE Report 22-15 (1976)

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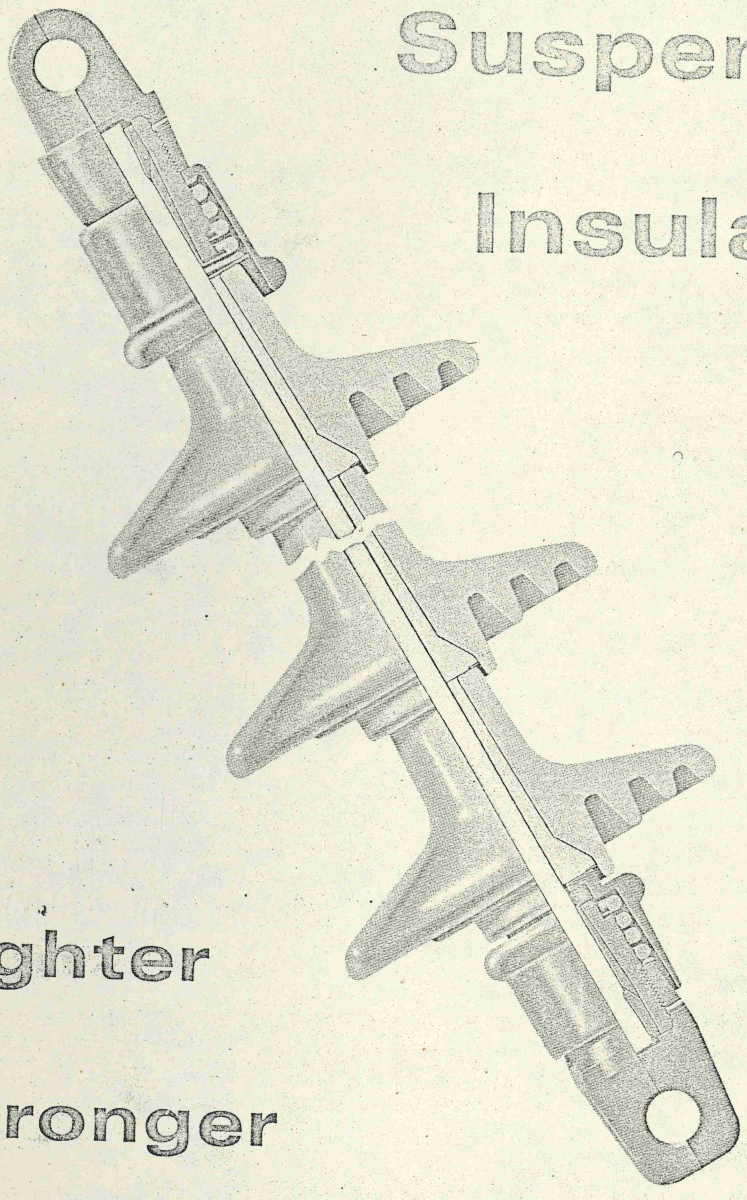
Unitary Suspension Insulator



- Lighter
- Stronger

Utility preferred products by

JOSLYN

Mfg. and Supply Co.

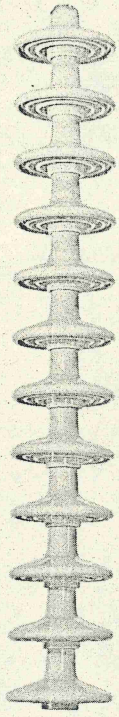
PINCO DIVISION

CATALOG 302-69

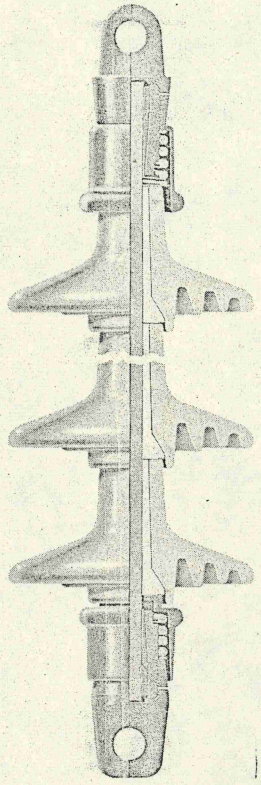
Unitary Suspension Insulator*

THIS FIBER GLASS ROD + THIS SPECIAL PORCELAIN = JOSLYN USI

HOLDS THE LOAD

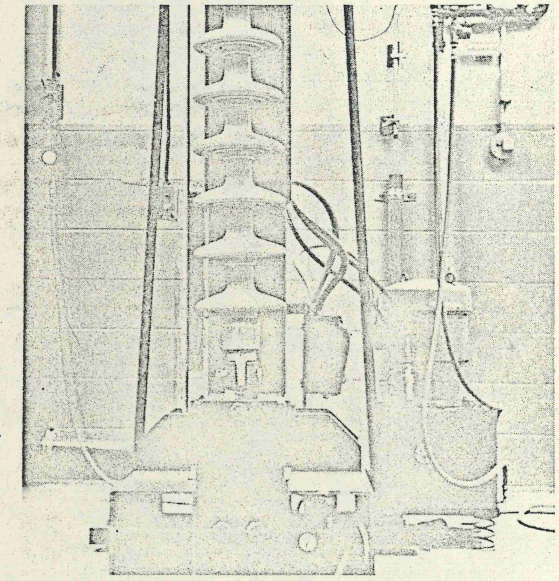


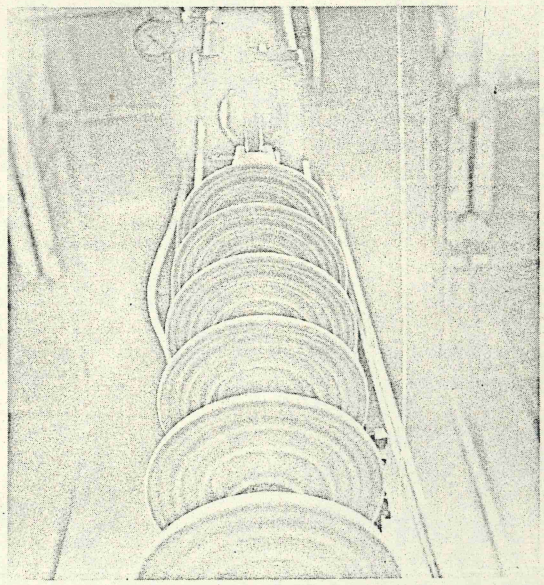
HOLDS THE VOLTAGE



A LIGHT WEIGHT COMBINATION

100% Proof Tested





After assembly on jig (left), a tension of 40,000 pounds is applied (right) to Proof Test the entire insulator.

*Patents Pending

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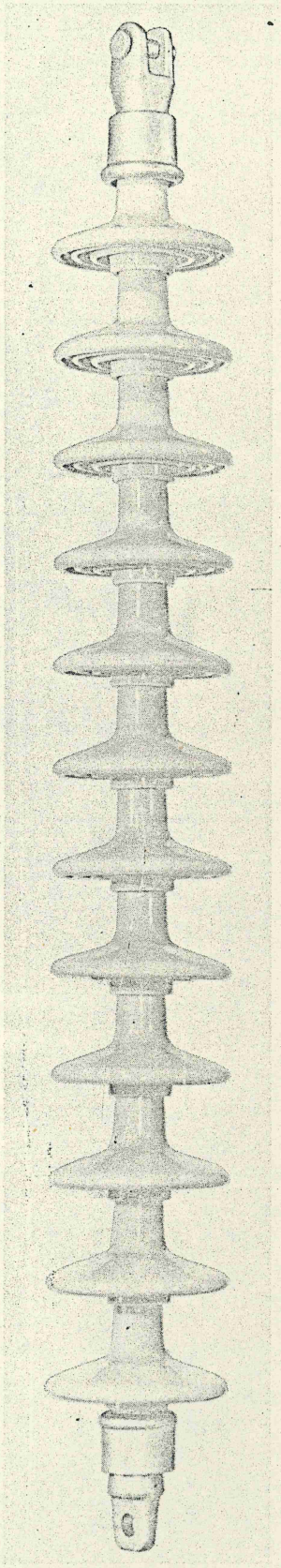
The only conductor support device that's individually Proof Tested at 40,000 pounds as an integral part in manufacturing.

By combining the exceptional strength of fiber glass with the demonstrated capability of porcelain's weather resistance and trackfree characteristics, Joslyn presents a unique suspension insulator.

LOOK AT THESE FEATURES:

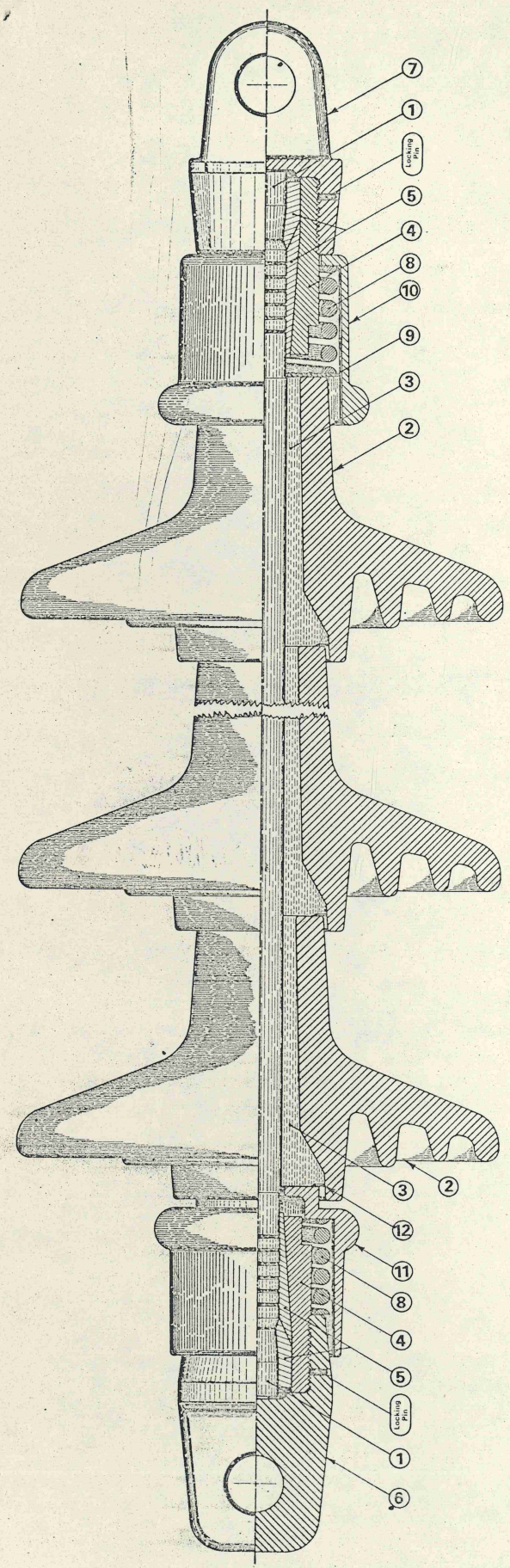
- Proof Tested at 40,000 pounds
- 40% lighter than conventional insulators
- 8¾ inch diameter for trim appearance
- Longer leakage distance
- Easier to clean
- Easier to handle; no cradle required
- Mechanically, one may do the job of two conventional insulator strings resulting in lower cost and improved appearance
- Eliminates line dropping due to porcelain breakage

Construction of the Joslyn USI consists of a strong 0.85" diameter fiber glass rod which provides mechanical support for the conductor. The porcelain insulator skirts provide the electrical insulation and protect the fiber glass rod. The porcelain skirts do not share any of the mechanical load. End fittings are high-strength forged steel, specially designed for the 40,000 pound Proof Tested assembly.



12-Shell USI.
71 inches long.
Weighs 96 lbs.
See page 6
for characteristics.

Unitary Suspension Insulator



1. Fiber Glass Rod (Polyester)
2. Horizon Glaze* Porcelain Shell
3. Elastomer Filler
4. Slip-Wedge Retainer (Steel)
5. Collet & Ring (Zinc)
6. Tongue Fitting (Forged Steel—Galv.)
7. Clevis Fitting (Forged Steel—Galv.)
8. Elastomer Compression Spring (S.S.)
9. Top Spring Support Washer (S.S.)
10. Upper Spring Cover (Cast Iron—Galv.)
11. Lower Spring Cover (Cast Iron—Galv.)
12. Elastomer Retaining Washer (S.S.)

ASSEMBLY

Each USI is factory assembled where Proof Testing is required in the assembly process.

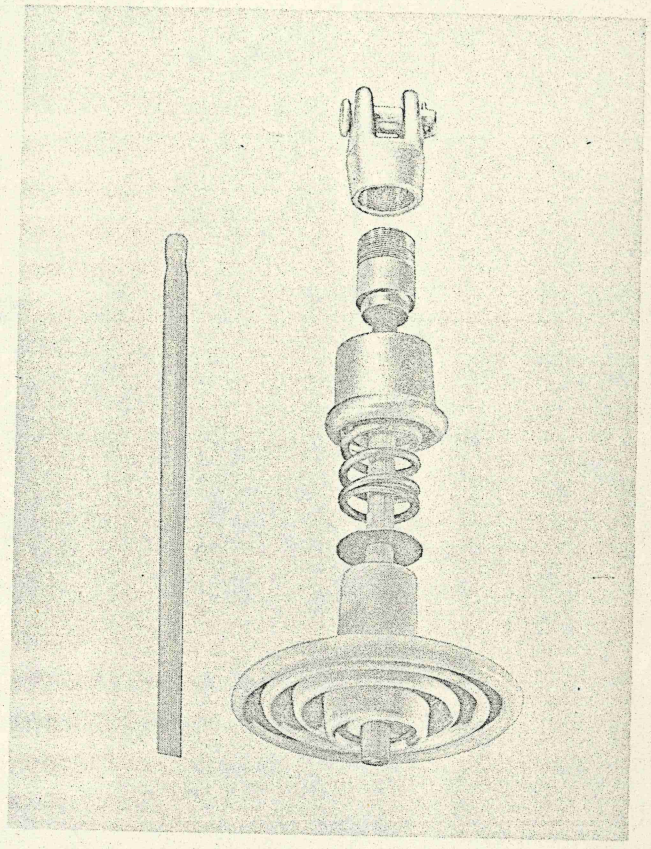
END FITTINGS

The specially designed, high-strength forged steel end fittings (6) and (7) are interchangeable during the manufacturing process.

Design–Construction–Assembly

MECHANICAL

The semi-flexible, load bearing fiber glass rod (1) is held in the rod retainer (4) by a slip-wedge device which is seated in a tapered collet by a force of more than 40,000 pounds. The gripping power of this fitting increases with load and approaches the ultimate strength of the rod.

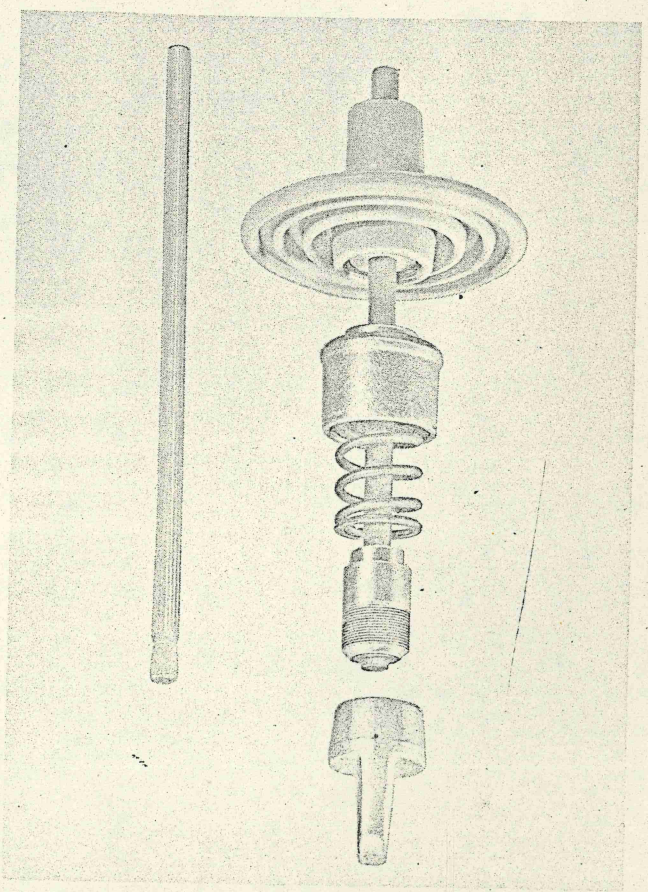


ELECTRICAL (Internal)

Internal electrical integrity and flexibility are maintained by an elastomer (3), under constant pressure from the compression springs (8). The dynamic loading of the elastomer assures a positive electrical seal and automatically compensates for expansion and contraction due to temperature changes.

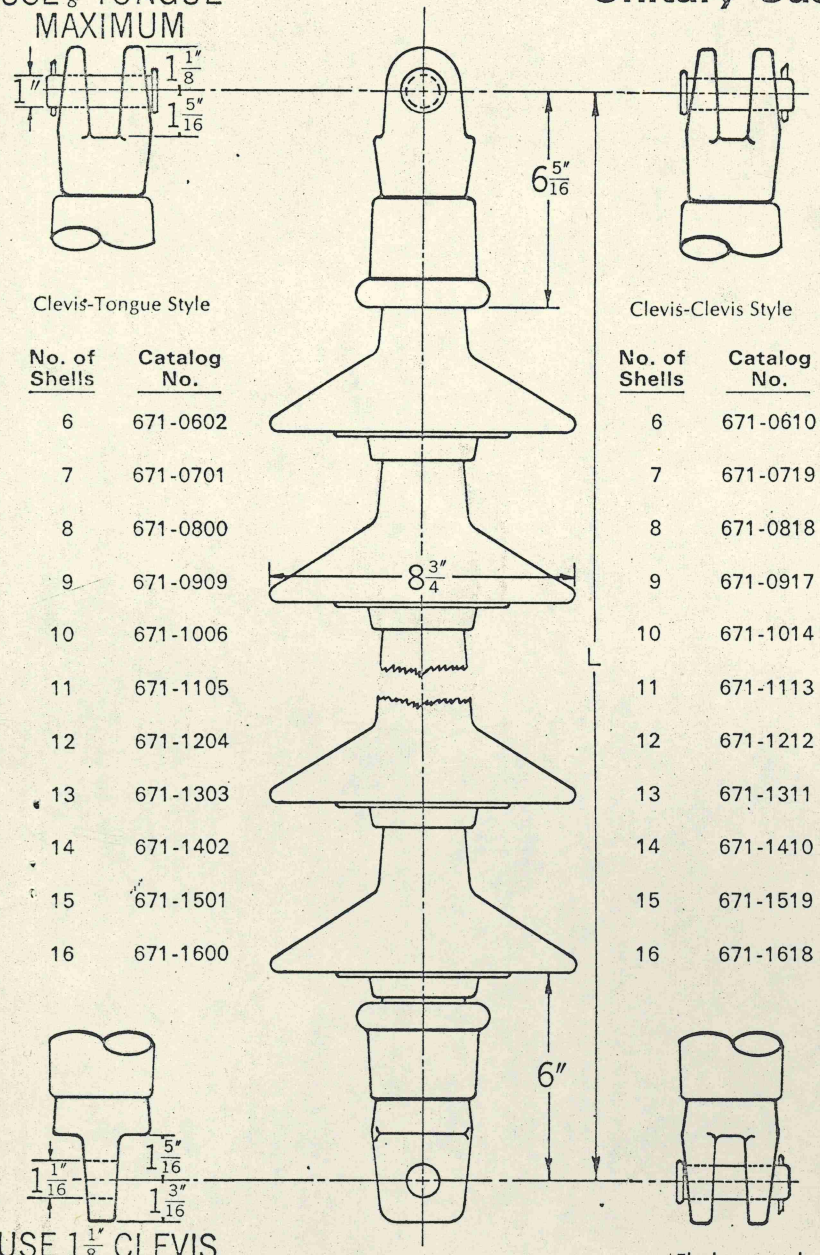
ELECTRICAL (External)

Eye pleasing Horizon Glaze* porcelain shells (2), with proven electrical properties, are used in the insulator. The porcelain surface is non-tracking, washable, arc resistant and weatherproof for maximum reliability. The USI design eliminates bulky intershell metallic hardware and keeps flashover away from the porcelain surface.



*Trademark of Joslyn Mfg. and Supply Co.

Unitary Suspension Insulator—Characteristics



Clevis-Tongue Style

No. of Shells	Catalog No.
6	671-0602
7	671-0701
8	671-0800
9	671-0909
10	671-1006
11	671-1105
12	671-1204
13	671-1303
14	671-1402
15	671-1501
16	671-1600

Clevis-Clevis Style

No. of Shells	Catalog No.
6	671-0610
7	671-0719
8	671-0818
9	671-0917
10	671-1014
11	671-1113
12	671-1212
13	671-1311
14	671-1410
15	671-1519
16	671-1618

Number of Shells	60 Hz.* Flashover rms. KV.		Critical* Impulse Flashover KV.		Leakage Distance Inches	Dry Arc Distance Inches	(L) Length Inches	Weight Pounds
	Dry	Wet	Pos.	Neg.				
6	310	270	585	570	76	33	41	58
7	355	325	670	655	89	38	46	64
8	405	370	750	730	101	43	51	70
9	455	410	825	805	114	48	56	77
10	505	455	905	885	127	53	61	83
11	560	500	980	960	140	58	66	90
12	605	540	1055	1035	152	63	71	96
13	655	580	1125	1105	165	68	76	102
14	695	620	1195	1175	178	73	81	109
15	735	655	1270	1250	191	78	86	115
16	780	690	1335	1315	203	83	91	122
Two Section Assemblies								
17 (8 + 9)	870	745	1440	1425	216	90	107	148
18 (9 + 9)	915	780	1510	1490	229	95	112	155
19 (10 + 9)	955	815	1575	1555	242	100	117	161
20 (10 + 10)	995	855	1640	1620	255	105	122	167
21 (10 + 11)	1035	890	1705	1690	267	110	127	174
22 (11 + 11)	1085	925	1770	1755	280	115	132	180
23 (12 + 11)	1120	960	1840	1810	293	120	137	187
24 (12 + 12)	1165	990	1905	1870	306	125	142	193
25 (13 + 12)	1200	1025	1965	1935	318	130	147	199
26 (13 + 13)	1240	1055	2030	2000	331	135	152	206
27 (14 + 13)	1280	1090	2095	2060	344	140	157	216
28 (14 + 14)	1320	1120	2160	2120	357	145	162	219
29 (15 + 14)	1375	1150	2225	2185	369	150	167	225
30 (15 + 15)	1400	1185	2290	2245	382	155	172	231
31 (16 + 15)	1435	1215	2355	2310	395	160	177	238
32 (16 + 16)	1470	1245	2420	2370	408	165	182	244
Three Section Assemblies								
33 (11 + 11 + 11)	1555	1275	2525	2470	420	173	198	270
34 (11 + 11 + 12)	1590	1305	2590	2535	433	178	203	276
35 (11 + 12 + 12)	1625	1335	2655	2595	446	183	208	283
36 (12 + 12 + 12)	1660	1360	2720	2660	459	188	213	289
37 (13 + 12 + 12)	1690	1390	2785	2720	471	193	218	295
38 (13 + 13 + 12)	1725	1415	2850	2785	484	198	223	302
39 (13 + 13 + 13)	1760	1440	2915	2845	497	203	228	308

*Flashover values are based on tests conducted in accordance with ASA standard C29.1 with insulator mounted vertically.

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Survey of new insulation methods

Companies reveal their operating experiences with new plastic and fiberglass line insulators

By Merlin F. Wadsworth, Senior Transmission Engineer, Tampa Electric Co., Tampa, Fla.

◆ As the pressures continue to increase on the utilities to beautify or go underground with transmission lines, new techniques of insulation have been appearing on the market in recent years. Hopefully, these methods will successfully meet the criteria of being eye appealing while still maintaining the reliability of the more proven methods. This paper is a summary of the success or failure of some of the new methods as reported in a survey.

The information for this survey was compiled from answers to a questionnaire which was sent to all of the 24 members of the Southeastern Electric Exchange, Transmission and Large Substation Section. Several questions were asked dealing with the use of new methods of insulation at the transmission voltage levels. Twenty-three of the companies responded, and of these, 17 had used plastic or fiberglass insulation for transmission lines.

Experimental and standard

The installations by these companies were both on an experimental basis and as a standard of construction. The two major types of insulation reported on were the epoxy-type polymer insulator and the epoxy-fiberglass rod in series with porcelain or toughened glass insulators. One company reported an installation using the epoxy-type polymer in series with porcelain. The 17 companies that used these new methods of insulation reported on 32 different installations; of these 32, 16 were considered to have successful operating records and 16 had unsuccessful operating records.

No attempt is made to discuss the relative merits of each type of insulation nor is any inference made from the answers received on the questionnaire. The information is factually reported in a summary of the results in the following paragraphs.

Epoxy-type polymer

Out of the 12 installations of the epoxy-type polymer insulator, 11 had unsuccessful operating records. The one company which reported no trouble to date had 3 units installed in the horizontal deadend position. These units have been in service for 5 years. These 12 installations consisted of a total of 496 units, 420 of which were installed by one company. The other installations were in small quantities on an experimental basis only. These companies, all 10 of which reported problems with these units, have removed from service all of the units on their systems. The company which had 420 units installed, has removed all suspension units and retained 222 units in service in strain strings on which they had no problems. This is consistent with the problems which arose on all installations.

The majority of the units causing problems were installed in the vertical suspension position. The major problem was surface tracking. The tracking caused carbonization of the units which gradually increased to the point of flashover or puncture of the skirts on the unit. Eight of the 11 installations were credited with causing one or more outages.

Many of the units were installed in contaminated areas and the life of those which failed was dependent on the amount of contamination. The fact that the horizontal units performed better than those in suspension, seems to support the theory that insulators in horizontal strings perform better in contaminated areas than do those in vertical strings. The life ranged from several months to 6 years for those units which failed; the mean life approximated 2 years. The operating voltages of the installations were 69 kV, 115 kV, and 138 kV.

Epoxy-fiberglass rod

The other major category of plastic and fiberglass insulation reported on by the companies answering the survey was the epoxy-fiberglass rod in series with porcelain or toughened glass insulators. The voltage range of these installations was from 23 kV to 230 kV.

There were 20 different installations of this type of insulation; four of these had unsuccessful operating records and 15 were reported to be operating satisfactorily. One installation included in the table of unsuccessful operations was not having problems but was included in that table because the units had been removed from service and the reporting company did not plan to use this type of unit in the future.

The four installations having problems consisted of a total of 1454 units installed at voltages of 69 kV, 115 kV and 138 kV. The

(Continued on page 99)

ing of Negroes, Mexican-Americans, and other minorities, but quotas are not set.

Construction safety legislation enacted

Congress has passed, and the President has signed, legislation letting the Secretary of Labor set safety standards for federal and federally-aided construction.

Now, President Nixon is asking Congress for even broader legislation to let the Administration set safety and health standards for almost all industries. (Excepted would be industries that presently have federal safety programs, such as mining and longshoring.)

A National Occupational Safety and Health Board appointed by the President would set these standards, and would adopt standards of industry groups where "the standard-setting organization possesses high technical competense and considers the views of all interested parties in making its decisions." In states with as good or better safety procedures than the federal government's, state standards would obtain.

Insulation methods

(Continued from page 77)

majority of the units were on one installation of 1000 units at 115 kV. Two of the four installations were credited with causing one or more outages; in both of these installations the outages were caused by flashover of the fiberglass rod. On the other two installations, one was unsuccessful because of severe surface tracking and one unsuccessful because the coating of the fiberglass failed under ultraviolet exposure. Of the original 1454 units installed, 1104 have been removed from service.

The 15 installations which had successful operating records, consisted of a total of 3816 units of various configurations at voltages of 23 kV to 230 kV. The majority of these units were on one installation of 2468 units operating at 230 kV. This particular installation consisted of an epoxy-fiberglass suspension link 60½ inches by 1½ inches with six 5¾-inch by 10-inch insulators in vertical suspension and in vee-string. This installation has been in service for 2 years without any problems. The other installations operating successfully have been in service from 6 months to 3½ years.

Heavy equipment

(Continued from page 36)

stalled in the state, and the second involves a training facility for National Airlines. This last project will include the largest electrical generator ever installed in the Miami area.

Construction in south Florida continues at a break-neck pace and the pattern is reflected by the business volume chart in Brock's office. Forecasts indicate a record year with a whopping backlog of signed contracts forcing the anticipated gross right off the chart.

"At the moment, we're aiming for a $2.5 million year," smiles Jack Brock. "Hardly any of that will be under roof. Maybe it pays to work in the sunshine."

Demand metering

(Continued from page 76)

most frequently used in totalizing demands.

Another company uses meter A on motor loads up to ten horsepower.

Installation of meters B and C are usually on special contract although there is no set rule.

(9) Is magnetic tape used for customer billing?

To this question 29 reported no, and none reported yes.

(10) Is it used in interchange metering?

One reported yes, and 28 reported no.

(11) Is it used for statistical reasons?

Seven said yes, and 21 said no.

(12) When asked the type of pulse equipment, the results were as follows:

(A) Twenty-seven used mechanical contacts.

(B) Twenty-six used pulse generators. One company is changing to pulse generators on interchange metering hoping to reduce maintenance

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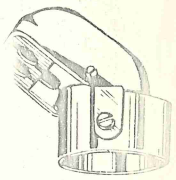
3 No. 4/0 Al. (28



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x 2" 200 amp.
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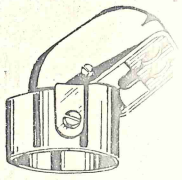
lo. 4/0 Al. (282



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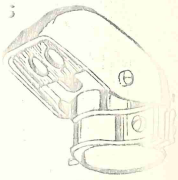

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CHARACTERISTICS OF FIBERGLASS AND POLYMER INSULATION

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Jung Hotel
New Orleans, Louisiana

CHARACTERISTICS OF FIBERGLASS AND POLYMER INSULATION

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INTRODUCTION

Although today we tend to think that porcelain line insulation has always given satisfactory operation, there really are several things historically not quite right with that point of view. For the first thirty years or so of its use, porcelain insulation was unreliable all too frequently. Fortunately, utilities and manufacturers alike learned the problems of porcelain, and designed the product and use of it to accommodate these shortcomings. Nowhere has that been truer than in suspension insulators. From the manufacturer's viewpoint, the product is slow to manufacture, heavy, and can be fragile if handled roughly. Designs and processes must reflect the inherent nature of the materials used. The utility is concerned with its bulkiness and weight, and must allow considerable warehouse space for its storage. The suspension insulator's arch enemy has historically been the gun carrying vandal, but more recently the ecologist has turned our attention to the appearance of its bulky profile, and the clutter on the pole top that can easily be caused with several porcelain discs in series.

Seventeen years ago we began to study outdoor high voltage insulation, asking whether some alternative might be found in the newer insulation materials. What developed from more than a decade of research and development has come to be known as the GEPOL® insulator. (Figure 1)

The GEPOL insulator is, properly speaking, a track-resistant, fiberglass reinforced polymer insulator. It depends for its electrical and mechanical integrity on a fiberglass reinforced central rod, about which is cast the track-resistant material, a flexibilized epoxy formulation.

It would have been possible to make a plastic insulator along these general lines twenty years ago. It would not have worked, however. Scientists and design engineers have known for many years that almost all organic materials will track when exposed to contamination and moisture outdoors in electrical service. Tracking may be defined as the formation of carbonaceous conducting paths on the surface of

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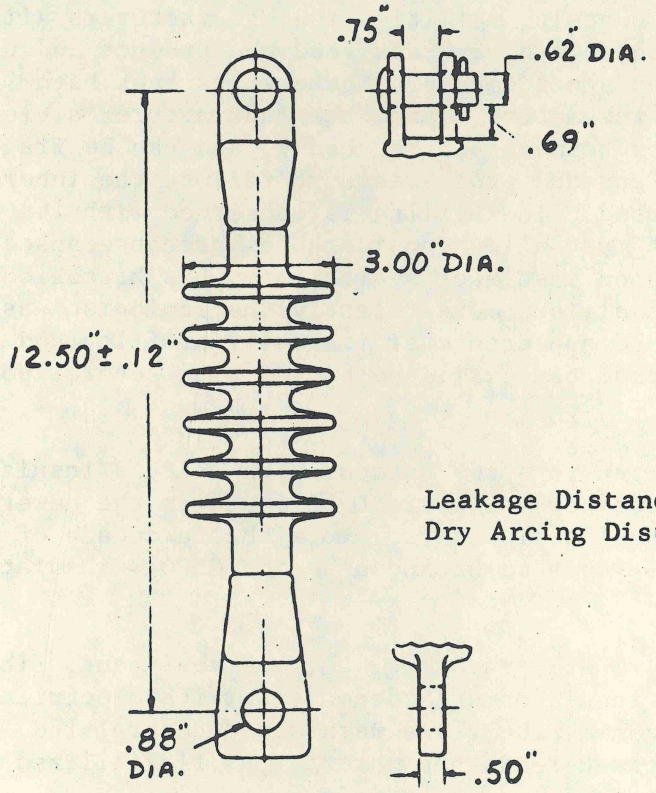


Leakage Distance, In.	14
Dry Arcing Distance, In.	7-3/4

Figure 1 -- 15 KV GEPOL Insulator Dimensions

insulators, and is caused by high leakage currents on wet, contaminated insulators. It was not until 1954, when General Electric scientists discovered the track-resistant properties conferred by hydrated alumina filler upon many polymeric systems, that the way became open for ultimate success. The basic novelty and benefit of this discovery was recognized in a series of patents granted by the United States and numerous foreign countries. The action of hydrated alumina appears to be due to the water released from the hydrate at the high temperatures ($>200^{\circ}C$) leading to carbonization. The water reacts at these temperatures with the carbonaceous materials, forming carbon monoxide and hydrogen. These two gases are volatilized and no track remains.

More work was required, however, to develop this basic idea to a level of commercial acceptance. Three general areas were found to be critical in this project, and each has received some years of attention. This paper will discuss briefly some of the many facets of this extensive development program. It was as a result of this laboratory work, many field trials, and finally widespread use, that today's GEPOL insulator has been proven successful for distribution voltages and installation practices.

ALTERNATIVES TO PORCELAIN SUSPENSIONS

Before we discuss the various necessary aspects of the distribution polymeric insulator, we might pause to consider what possible alternatives there were to porcelain in the 1950s. Fifteen years ago fiberglass reinforced structures were becoming well-known. We theorized that it should be possible to use one fiberglass rod of sufficient length for the entire insulator string, with only two rather small pieces of hardware, one on each end. This reduction in hardware joints should lead to improved RIV performance, because of greater electrode separation. Laboratory investigation quickly proved that although such rods are satisfactory for guy strain application, they are not track-resistant and are therefore completely unsatisfactory as primary insulation.

The next logical step was to give the fiberglass rod a track-resistant surface. Since we are porcelain manufacturers, our thoughts were to use porcelain discs with through holes in the center, so the discs could be stacked up along the length of the rod. A moment's reflection, however, indicates that though this does reduce the amount of expensive metal, it does nothing toward eliminating the weight and fragility of the porcelain. In fact, since the modular suspension unit is replaced by a much longer single insulator, the weight and general bulkiness is worse than in the standard unit, insofar as easy handling goes. It was at this point that it was decided to go the whole way to develop an entirely polymeric suspension insulator.

LABORATORY DEVELOPMENT WORK

As mentioned earlier, three fields of development were needed: materials for the insulation, hardware connection, and general shape of the sheds and insulator. Porcelain insulator technology was of rather little help, except that numerous test methods were ingrained in the industry; and any new product would be expected to conform to the standards used for porcelain, in test methods, quality and reliability.

The fiberglass rod is the basic element of the materials used in the polymer suspension insulator. It must be consistently electrically sound, and of a size sufficient to give the desired mechanical strength. This seemed a simple matter, but finding rod sources who could supply quality of the levels we set, and do so for the miles of rod needed, was not so simple. Some years of joint development of rods with several manufacturers were needed to overcome the problems of composition and satisfactory processing required to give high levels of quality and reliability. Today both epoxy and polyester rods of outstanding quality are possible, and either of these two basic resins can be used, if formulated, processed and cured properly.

The hydrated alumina filler used to achieve track resistance has already been mentioned. It was the single most important step required in the development program for the outer portion of the insulator, but was not the only one. The earliest epoxy resins, chemically known as the bisphenol-A epoxy resins, were greatly improved by the use of hydrated alumina. In the early 1960s, however, the newer cycloaliphatic epoxy resins were commercialized and proved to have inherently better electrical, outdoor, and track-resistant properties than do the bisphenol-A versions. Using the hydrated alumina and cycloaliphatic epoxy resins together gave outstanding track resistance in accelerated laboratory tests. In field use, we have never had a known case of tracking with this combination, with many tens of thousands in service.

One further requirement must be made of the outer material of the insulator: it must be somewhat flexible to withstand temperature cycling and overcome potential problems of brittleness and fragility. In addition, since it is bonded directly to the fiberglass rod, the outer material must be able to match the rod's expansion arising from the mechanical loads and temperature changes. Unmodified cycloaliphatic epoxy resins cured with conventional agents are generally glassy, brittle products, usually even more so than the related bisphenol-A epoxy systems. This brittleness may be overcome by use of a flexibilizer, but it is necessary to choose carefully so that no other property is compromised by this addition.

The earliest hardware attachment method used socket type hardware over the protruding ends of the fiberglass rod. A dozen years of field experience on utility lines has demonstrated the correctness of this approach. At one point we tried to use hardware which was connected inside the insulator to a fiberglass rod with loops on its ends. Although this led to high strengths, it unfortunately gave considerable difficulty in manufacturing insulators that were void free in high electrical stress areas.

The third major development area, shape of the insulator, particularly the sheds, is one that is still continuing for vertical transmission use. However, for distribution, which is entirely an horizontal application, a simple sinusoidal shape for the sheds has proven excellent in lab and field experience. Such a design allows maximum cleaning by rain, and sufficient leakage distance for all degress of contamination. Because the polymer unit is so lightweight, the insulator can be made in one piece, rather than modular. It is easily handled by the lineman, and requires no joining together of the sort done with porcelain discs.

FIELD EXPERIENCE

Our field experience is now twelve years old, and has been gained at voltages to 230 KV and beyond. Four basic units have been subjected to field trial: one designed for 115 KV, one for 69 KV, one for 34.5 KV, and one for 15 KV. Of these only the 15 KV unit has been commercialized, but higher voltage distribution units are planned for commercial release later.

The 69 KV unit was the first of all the field trials, and was surprisingly successful. Most of the units are still in service today, after twelve years. Those that have failed were all in the vertical position: we now know this was partly a matter of the early materials used, and partly a matter of shape.

The 115 KV field trial was the largest, best publicized in reports to the industry, and least successful. Not only did it suffer from use of the early resin systems, but also from poorer hardware connection methods and shed design than the earlier 69 KV unit had. If nothing else, it proved that it was very difficult to rely at that time on laboratory tests alone for evaluation, for these changes looked good when tested in the laboratory.

The 15 KV insulator design and application features greatly benefited from the earlier trials at higher voltages, particularly as we had come to recognize the significant difference between results obtained in the horizontal position as contrasted to the vertical. The 34.5 KV suspension unit has been in field trial now from two to three years at numerous locations around the country, without problems in the widely varying application conditions selected. Results should be

similar to those of the 15 KV insulator, for all distribution voltage applications are horizontal for suspension insulators.

POLYMER INSULATOR CHARACTERISTICS

So much for the history of the development and the proper components of a useful suspension insulator. What really counts for utility use is the features that can be obtained in a polymer-fiberglass insulator. Perhaps it is easiest to group the advantages into three major areas: mechanical, electrical, and other.

The polymer insulator offers mechanical strength ratings equal to the conventional proof test and M&E values of porcelain. In general the range of ultimate strengths obtained in a test sample is less for GEPOL than for porcelain, due to the less variable nature of the fiberglass rod compared to porcelain. Torsional strength, though not a rated value in suspension insulators, is a potential problem in any clevis type structure. The GEPOL insulator has a torsional strength equal to that typically obtained with 4-1/4" or 6" porcelain suspensions. Impact strength for the polymer unit is far greater than porcelain's--really not even comparable. Brittleness, fragility and thermal shock problems simply do not exist in the GEPOL insulator, whereas they are quite serious with porcelain when it is roughly handled, dropped, or shot at by vandals.

Many of the electrical ratings of the GEPOL insulator are quite similar to those required of two 4-1/4" or 6" porcelains. (Table 1). Wet flashover, however, is markedly superior in the polymer case. Puncture strength is very high: typical ultimate puncture values are around 240 KV, and of course can only be obtained under oil since they are far above the flashover strength. Even in oil, the unit usually flashes over rather than puncturing. This outstanding puncture strength is directly related to the long puncture path relative to the flashover path, as opposed to a quite short puncture path in porcelain suspensions. Although rated the same as porcelain, the radio and TV noise characteristic is another markedly better property in a polymer-fiberglass unit, and is related to the much greater separation of the electrodes in the insulator.

Among the other properties, weight and volume are reduced over 70% for the polymer insulator. These features are important in shipping, in warehousing, and in installation. Another installation advantage is in the single unit nature of the polymer insulator, which eliminates problems of handling two units joined together, with their tendency to flop one way or the other while being handled. Also important to the lineman is the small diameter, which is more readily covered while working it hot on the line.

Table 1

ELECTRICAL COMPARISONS

RATED PROPERTY	REQUIRED FOR 15 KV SYSTEM	15 KV GEPOL
60 Hz Flashover		
Dry (KV)	80	100
Wet (KV)	45	75
Impulse Flashover		
Positive (KV)	130	150
Negative (KV)	155	175
R.I.V., Max. (μv) @ 10 KV, 1000k Hz	100	50
Puncture, Min. (KV)	115	150
Arcing Distance (In.)	6-1/4	7-3/4
Leakage Distance (In.)	12	14

Table 2

OTHER APPLICATIONS

AIR-BLAST BREAKERS

-- 500 KV CT COLUMNS
-- 230 KV CT COLUMNS AND HORIZONTAL BUSHINGS

BUSHINGS

-- TRANSFORMERS
-- NETWORK PROTECTORS

VACUUM INTERRUPTER HOUSINGS

OPERATING CONTROL RODS -- SWITCHGEAR

PIN INSULATORS

RADIO TOWER INSULATORS

15 KV GEPOL IN-LINE SWITCH INSULATORS

Certainly among the other advantages should be listed the much slimmer silhouette and the resulting less cluttered appearance on the pole. This same slimness also makes the insulator a far more difficult target for the vandal, which coupled with the lack of fragility, makes the polymer unit virtually indestructible.

APPLICATIONS

The use of fiberglass-polymer insulators for distribution service has been evaluated by over 400 utilities, and accepted for use in significant volume by many. We anticipate that the number of those utilities specifying the polymer unit for use in their systems will continue to grow. Our plans and programs for further development are, of course, contingent upon wide acceptance by the utilities.

The General Electric Company is continuing its programs to expand the use of polymer insulators into higher voltage suspension applications. As mentioned above, higher voltage distribution suspensions will be commercially available later. Transmission studies are underway in our laboratories and outdoor sites, as well as at several cooperating utilities. Initial experiments, largely concerned with shed design, are very encouraging, but we will not commercialize any transmission product until sufficient field trials of several years' duration have demonstrated success under all conditions of use.

The 500 KV air-blast breaker housings manufactured in 1965 have been mentioned frequently in various speeches and papers since then. These experimental fifteen foot high housings continue to be the world's largest one-piece insulators ever made of any kind of material. More recently, we have made field trials of 230 KV breakers in which additional porcelain components were replaced by fiberglass-epoxy insulators. Both the 500 KV and 230 KV polymer insulator breakers are in active use at several utilities today.

We have also built experimental 115 KV bushings in which the usual porcelain housing has been replaced by a fiberglass tube covered with GEPOL. More work is planned with these and other high voltage bushing designs.

We have sold a number of other polymer insulator products for outdoor use in recent years. (Table 2). Though some are still in low volume, others have been sold by the hundreds or thousands. Our field experience from all the applications of the last five years has been uniformly excellent.

CONCLUSIONS

On the basis of all our laboratory and field experience with a wide variety of polymer insulator products, we believe that today, using properly formulated materials, carefully thought-out designs, and extensive laboratory and field testing, outstanding results can be obtained from fiberglass reinforced polymer insulators. Both the volume and variety of these modern insulators will certainly grow rapidly in the years ahead, as manufacturers and users together expand the designs and applications into ever-widening fields.

A COMPARISON OF GENERAL ELECTRIC'S GEPOL INSULATOR AND A. B. CHANCE'S EPOXILATOR

INTRODUCTION

Following a 13 year development program on plastic insulators for outdoor use at high voltages, the General Electric Company introduced its 15 KV Gepol strain insulator in February 1967. It was the first commercially available plastic outdoor insulator in the world: more than 60,000 were ~~sold~~ shipped to about 400 utilities during the next 3-1/2 years. Subsequent to introduction there were two changes made, in 1968.

In mid-1970 the A. B. Chance Company announced the commercial availability of a 15 KV plastic strain insulator, which it named the Epoxilator. The outward appearance of the product is very similar to the first version of the 15 KV Gepol.

By late 1970 we were able to obtain published characteristics of the Epoxilator, as well as commercially purchased units for test. Our planned test program covered mechanical, electrical, analytical, and other physical characteristics, based upon the applicable standards for porcelain distribution insulators as well as properties we have found pertinent to plastic insulators.

PUBLISHED CHARACTERISTICS

The published characteristics for strain 15 KV Gepol insulators, Epoxilators, and code requirements are shown in Table I.

TABLE I

PUBLISHED CHARACTERISTICS

Property	Required for 15 KV System	General Electric GEPOL	A.B. Chance EPOXILATOR
Catalog Number		10P012	C654-0000
MEE, Lbs.		10,000	10,000
Test, Lbs.		5,000	5,000
Leakage, Distance, In.	12	14	--
60 H_z Flashover, Dry, KV	80	100	100
60 H_z Flashover, Wet, KV	45	75	75
Impulse Flashover, Positive, KV	130	150	140
Impulse Flashover, Negative, KV	155	175	180
60 H_z Positive, KV	115	150	--
RIV @ 15 KV, 1M H_z, μV Max.	100	50	--
Net Weight, lbs.		3-1/4	1-3/4

PUBLISHED CHARACTERISTICS (Continued)

Our examination and testing of the units showed both products meet the value of the properties claimed in their publications. The leakage distance of the Epoxilator was measured as 15-1/8", the same as the actual measured distance of the Gepol insulator. Puncture and radio interference voltage values for the Epoxilator also met the code requirements, though apparently no published rating has been made by Chance. On this basis, the two products would appear essentially equivalent. However, our long experience in developing and testing Gepol insulators in the laboratory and in the field has demonstrated many times to us that this published list of properties is not sufficient to define a satisfactory plastic product for outdoor insulator use.

FURTHER CONSIDERATIONS

A suggestion of an important difference between the Gepol insulator and the Epoxilator can be noted in the weights of the two units. The obvious answer is that the Epoxilator uses lighter weight cast aluminum hardware, rather than the malleable iron used on the Gepol insulator. Further investigation, however, shows that this alone does not account for the weight difference. The difference in weight arises because the Gepol insulator's sheds (the "body") are made of a "filled" plastic composition, while the Epoxilator is made of a less dense, unfilled composition. This is a most significant difference. The Gepol insulator body composition and the Epoxilator body composition are compared in Table II, to the extent we have analyzed the Epoxilator to date.

TABLE II

GEPOL AND EPOXILATOR BODY COMPOSITIONS

Material	GEPOL	EPOXILATOR
Base Resin	Cycloaliphatic epoxy	Bisphenol-A epoxy
Hardware	Anhydride	Anhydride
Modifier	Flexibilizer	None?
Colorant	Grey plus opacifier	Grey plus opacifier
Filler	Hydrated alumina	None

FURTHER CONSIDERATIONS (Continued)

A major part of the outstanding record of the 15 KV Gepol insulator for resistance to tracking and erosion (not one field problem was reported by a customer or found in our testing programs) may be credited to the Gepol composition. Gepol's cycloaliphatic epoxy resins are known to be inherently superior to the older, bisphenol-A epoxy resins. To this basically superior resin we add hydrated alumina in significant quantities, based upon a General Electric patented invention. The improvement in tracking and erosion resistance given by hydrated alumina has been accepted around the world as a significant advancement in plastics formulation, and has been patented by us in all the major manufacturing countries of the world.

BURNING, TRACKING AND EROSION TESTS

When we found the lighter weight of the Epoxilator was due to the lack of hydrated alumina, or indeed of any filler, we investigated the burning, tracking, and erosion resistance of the Epoxilator. One of the chief problems in developing Gepol as it is today was the necessity that we overcome the tracking and erosion problems plastics have historically had in outdoor application at high voltages. Tracking is the formation of carbonized tree-like paths across the surface of the insulator: erosion is the disappearance of material from the surface, usually leaving a pitted surface behind. Both tracking and erosion are due to electrical leakage currents flowing across the insulator surface, particularly when the insulator is wet and dirty. Many laboratory tests have been promoted to measure the resistance of plastics to tracking and erosion. Some of these tests are designed strictly to evaluate materials, while others can be made on finished insulators. In all cases, however, the measure of success is the resistance to burning, carbonization of the surface, and erosion.

The simplest test is exposure to flame. Materials may be defined as non-burning, self-extinguishing, or burning. Plastics generally will burn, if exposed to an open flame, though with widely different degrees of flaming. Gepol is self-extinguishing: it is very difficult to char, even in the flame of a propane torch, and all burning ends when the ~~track~~ torch is removed. The Epoxilator can be set afire with a match, and does not extinguish when the match is removed: the difference is truly remarkable compared to Gepol.

BURNING, TRACKING AND EROSION TESTS (Continued)

Of course it can be argued that actual flames are not often encountered, though pole fires are common in some areas. We therefore tried a wet withstand test on both insulators. In this test the voltage is held just below flashover while water is continuously sprayed over the unit. As time passes, there will be flashover, and the voltage is then reduced sufficiently to stop flashing over. In the Gepol case the voltage over a 10 minute period leveled off at about 75% of its startup voltage and was held there an additional 5 minutes. No damage occurred to the unit. The Epoxilator in 8-10 minutes fell to 20% of its startup voltage and burned rapidly when the voltage and water were turned off at the end of this time. We next ran dry flashover tests on both types of units. The Gepol insulator can be flashed over innumerable times without marks of any kind being left on the plastic material. The Epoxilator, however, will be drastically blackened by each shot, particularly on the sheds nearest the hardware fittings. Finally, as an even milder test, we subjected each unit to the standard three minute flashover test we use in our factory as a proof test of the electrical integrity of every suspension insulator we manufacture, porcelain as well as Gepol. The available current in this equipment is less than in our High Volt Lab flashover test. No mark of any kind was left on the Gepol (as is obvious from inspection of any Gepol insulator we ship), but the same test run in parallel on the Epoxilator left brown discolorations on it, due to mild carbonization of the body material.

These tests are possibly somewhat severe compared to normal line operation, as is any accelerated test. Our experience in plastic insulator development, however, is that these above tests are good basic screening methods for predicting long term field results. Formulations which do not pass these simple tests have done very poorly in outdoor service, particularly in contaminated conditions.

CONCLUSIONS

We have placed Epoxilator units on outdoor test in parallel with Gepol insulators, but some time will be required before problems can be expected to become obvious. In the meantime, we feel that any similarity of the Epoxilator to the Gepol insulator is superficial: there is no comparison between the two in resistance to damage caused by leakage currents over the surface. The Gepol insulator is far superior to the Epoxilator in laboratory tracking tests, and in addition the 15 KV Gepol insulator has nearly four years of commercial field

CONCLUSIONS (Continued)

experience without any problems due to burning, tracking, or erosion. Considering the long life anticipated by the utility customer for insulators, performance less than Gepol's will not be good enough.

GEPOL Insulators:

New Levels of Performance, Electrically and Mechanically

F. C. Vose, Mgr.—Polymer Insulator Engineering Insulator Products Dept., Baltimore, Md.

GENERAL ELECTRIC

GEPOL Insulators:

New Levels of Performance, Electrically and Mechanically

F. C. Vose,
Mgr.—Polymer Insulator Engineering
Insulator Products Dept.,
Baltimore, Md.

Polymer/fiber-glass dead-end insulators offer new peaks of resistance to burning, tracking, erosion.

A new concept in dead-end insulation for 15-kv distribution lines has been announced by General Electric Company. The development and field testing of a new insulator material offering superior electric and mechanical characteristics has spanned the past decade and culminated with in-service application of more than 65,000 insulators since 1967.

The early research and development work on materials was concerned with a wide range of non-ceramic insulation materials. The program gradually evolved to a study of the family of polymeric materials and it soon became evident that the epoxy resins provided the particular features being sought. After examining, testing and evaluating hundreds of different formulations, one which gave the optimum performance with regard to high resistance to track-

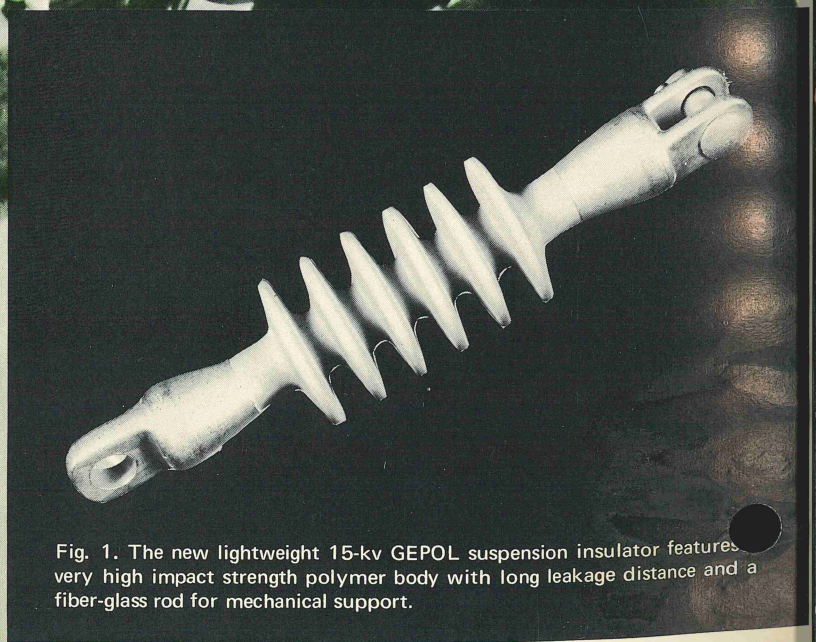


Fig. 1. The new lightweight 15-kv GEPOL suspension insulator features very high impact strength polymer body with long leakage distance and a fiber-glass rod for mechanical support.

ing, burning, and erosion, was selected. Insulators employing this modified epoxy resin are now identified as GEPOL® insulators.

Early laboratory tests of these new polymer materials for tracking qualities were conducted in salt fog chambers. As better materials were developed, problems were encountered with this test method because many of these organic materials did not deteriorate even after thousands of hours of testing. Thus, the rate at which improved formulations could be devised was curtailed by testing means. Obviously, a more severe test was needed. The solution came with the development of *The Standard Method of Test for Liquid Contaminant, Inclined Plane Tracking Used for Erosion of Insulating Material*, which has since been adopted as an industry standard (ASTM D2302-68). With this new test, improved materials could be readily identified. In this procedure, a contaminant is flowed over the surface of the material at a fixed rate while the material is under electrical stress. This is a much more severe test than the use of salt fog, and is probably more severe than any conditions found in field applications.

Exhaustive Testing

As improved materials were found, insulators of various designs were made and subjected to numerous laboratory tests as part of the learning process. Meeting this battery of tests did not necessarily mean success in coping with field conditions because it is impossible to duplicate all of those that might be encountered. But it did mean, after successful laboratory testing, that selected designs were good candidates for further testing on the outdoor electrical test facilities.

Finally, prototype insulators made of the new GEPOL material were produced in different configurations and were field tested on distribution lines in various parts of the country. See large color photo, left. Special attention was given to site selection to assure a wide range of operating conditions.

This testing program for optimum configuration for suspension insulators started in the field in the late 1950's and continued through 1968. During this period new product developments continued to be introduced. This total program culminated with the commercial introduction of the 15-kv GEPOL dead-end insulator — the first practical polymer insulator offered for regular distribution line use.

The fundamental concept of this insulator is that it is specifically designed for the strain support of an electrical conductor and is an integral unit, rather than several modular units. This results in an insulator which has metal parts for purposes of terminal connection only at the ends of an otherwise metal-free insulation module, as shown in Figure 1.

Design

This one-piece, high-impact-strength insulator has a central fiber-glass rod that provides the basic mechanical support for the unit. The ends of the fiber-glass rod are bonded to metal end fittings.

The molded skirts which provide the appropriate leakage distance for 15-kv insulators are made of a patented modified cycloaliphatic epoxy resin material which has excellent anti-tracking characteristics, very high impact strength, and maintains its superior characteristics through a wide temperature range.

The load bearing rod is mechanically, electrically, and chemically compatible with the polymer skirts so that a precision bond can be made between the two materials. Thus, the two major functions of the insulator — providing electrical insulation and mechanical strength — are performed solely by insulating materials.

The only metal parts in a GEPOL 15-kv dead-end suspension insulator are provided to attach the insulator to the distribution line and to the supporting structure. The ends of the fiber-glass load-bearing rod are designed to mate with the internal contour of the hardware. In addition, it is bonded to the hardware with a specially developed track resistant adhesive.

Test Program

To test the suitability of the entire insulator system mechanically and electrically, a rigorous testing program was devised. Some of the more important test criteria are shown in Table 1. Numerous polymer formulations were tested in this program before the final GEPOL insulator design was established and production started.

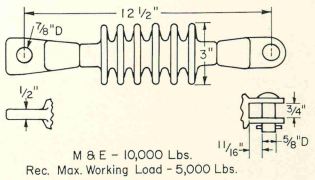
The 15-kv GEPOL dead-end insulator is designed to provide long and reliable service in both normal applications and in special duty applications. Special duty applications include use in areas with a high salt fog contamination, in areas where bulk deposit contamination is likely, in areas where the incidence of vandalism is high, or in locations of extreme climactic temperature. The significant characteristics of this new insulator are given in Figure 2.

In addition to the "in service" advantages of the GEPOL 15-kv dead-end insulator there are many other plus features. The high impact strength feature minimizes the risk of damage or breakage during installation. The compact design and light weight (75% less than conventional insulators) simplify storage and handling. Single-piece construction makes installation far easier than with insulator designs which require assembling components at the site. Maintenance is minimal because the special skirt contour and the self-cleaning feature of the polymer material inhibit contamination buildup and make the insulators self-washing.

Since their introduction four years ago, GEPOL insulators have been installed by more than 400 electric power utilities. During that time performance has been outstanding, with no reports of burning, tracking or erosion. Production facilities are being expanded and higher rated units are being developed, with 34.5-kv units now undergoing field trials.

Table 1. Test criteria for GEPOL insulator.

Thermal Shock: 32F to 212F, 10 cycles	
Thermal Cycling: -40F to 150F, 10 cycles	
Ultimate Strength at -40F	
Ultimate Strength at 150F	
Ultimate Strength after thermal shock	
Steep Front Impulse at 4000 kv per microsecond	
Cyclic Load: 20 cycles, 0 to 5000 lb.	
Time Load at 7000 lb.	
Short Circuit: 20,000 amp, 10 cycles	
Power Factor	
Water Soaking	
Long Time Overvoltage	



Leakage distance, inches	14
Dry arcing distance, inches	7¾
R.I.V. test kv RMS to ground	15
R.I.V. Max. Microvolts at 1000 khz	50
Impulse F.O. voltage, kv, Pos.	150
Impulse F.O. voltage, kv, Neg.	175
Low Frequency F.O. voltage, kv, Dry	100
Low Frequency F.O. voltage, kv, Wet	75
Low Frequency Puncture voltage, kv	150
Net Wgt, lb (malleable iron fittings)	3¼

Fig. 2. Characteristics and outline dimensions of 15-kv GEPOL suspension insulator.

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Rosenthal
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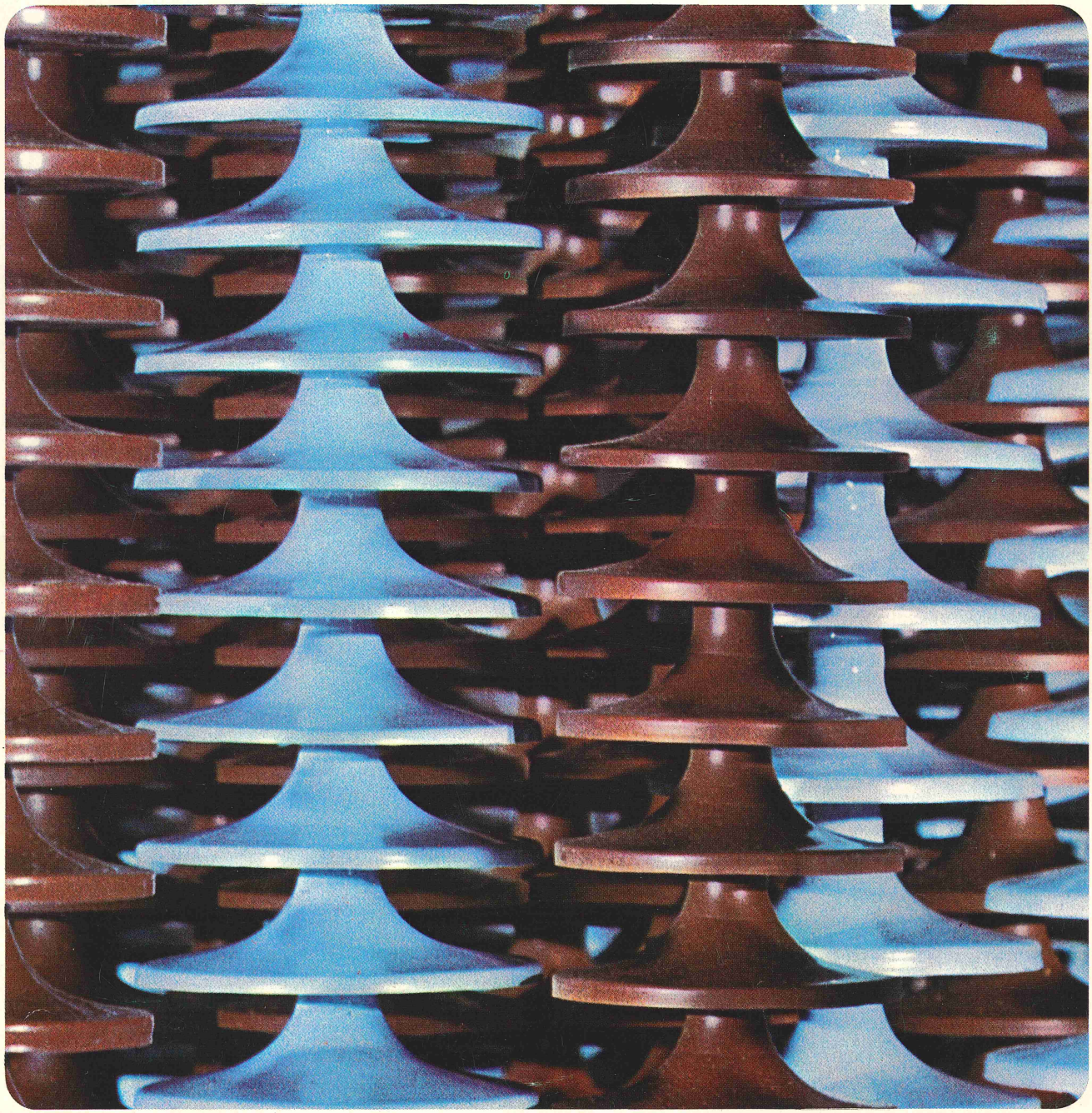
RODURFLEX-Kunststoffisolatoren für Freileitungen

RODURFLEX Plastics Insulators for Overhead Transmission Lines



A NON-PORCELAIN INSULATOR FOR TOMORROW'S CONSTRUCTION

Recent Materials Developments Make Lightweight Transmission Insulators Feasible

By

J. W. Elrod, EHV Application Engineer

H. G. Menzel, Marketing Manager

The Ohio Brass Company

INTRODUCTION – THE NEED

When the first 765-kv transmission lines were constructed the total weight of the insulator system became a significant factor in the mechanical design of the supporting structures. A quad-bundle tangent tower commonly used close to two tons of insulators. A deadend tower often used eight to nine tons of porcelain along with multi-string connecting hardware.

The next transmission level of approximately 1100-1200-kv can easily require six to eight tons of insulators and hardware per tangent tower. This dead weight required to support a multi-conductor UHV system is costly to install, expensive to support and introduces construction and maintenance problems.

Porcelain is now and has been for decades the accepted standard for high voltage insulation. The weight-to-strength ratio of porcelain was entirely satisfactory at lower transmission voltage levels. When the EHV level became a reality, a serious review was made of the multiple strings and the resulting strength-to-weight ratio requirements. This study clearly indicated that lighter weight and less complicated conductor support systems were not only desirable but were necessary for UHV construction.

Electrical insulation for overhead lines is provided by the surrounding air. The insulators maintain the necessary air flashover distance. The electrical function of an insulator is fulfilled if it does not become conducting under any conditions.

UHV insulation systems introduce the following requirements:

1 – Higher ratio of strength-to-weight.
2 – Life expectancy equal to porcelain now in use.
3 – Freedom from tracking and deterioration caused by surface leakage currents.
4 – Low maintenance and service requirements.
5 – Improved resistance to vandalism, especially gunfire.
6 – Economical overall cost to the user.

These requirements are easily defined and they may even be easy to obtain in a prototype model. Unfortunately, transmission lines are not built with prototypes. A new approach to insulation requirements must be one that can be faithfully reproduced month in and month out. It must be one whose variation in production – human or otherwise – can be kept under reasonable control.

DESCRIPTION OF THE DESIGN

This discussion covers a new and substantially different insulator design. It is a design that abandons the traditional ceramic material which has been used on electrical transmission systems throughout the years. The design abandons these in favor of new synthetic materials which achieve far higher strength-to-weight ratios in insulator construction. These materials will provide insulation reliability equal to that of porcelain under the rigorous environments of outdoor transmission service. This new insulator has been named Hi*Lite.

The Hi*Lite insulator takes two forms: a long rod style of suspension insulator and a horizontal line post. Design details of these insulators are outlined in U. S. Patent No. 3,898,372, issued August 5, 1975, and assigned to The Ohio Brass Company.

The structural member in both the suspension and the post is an epoxy-fiberglass rod of extremely high mechanical and dielectric strength. The weathersheds are made of a proprietary compound of EPM polymer using fillers to adapt it to the demands of electric power transmission. End fittings (steel forgings for suspensions and aluminum impact extrusions for posts) are directly swaged to both ends of the rod. The EPM polymer weathersheds are axially compressed between the end fittings. They are stretched over the rod using the unique properties of the polymer as a live followup. A very viscous silicone grease is used at the interface of the rod and the weathershed to prevent ingress of foreign materials.

HI*LITE SUSPENSION INSULATORS

The mechanical system of the suspension insulator consists of a single fiberglass rod with forged steel end attachments. EPM polymer weathersheds surround the central rod. The suspension insulators are made in one piece with no intermediate hardware.

A suspension insulator is primarily a mechanical support for an electrical conductor. It must be nonconducting and of sufficient size to provide the required air insulation distance. Fiberglass rod is close to ideal for the purpose. It is strong, light weight, and is a nonconductor.

The glass fibers in the rod have an ultimate strength of about 300,000 pounds per square inch. More than 50 per cent of the rod cross section is glass. Ultimate tensile strength above 150,000 pounds per square inch can be obtained when the glass carries all of the load.

The end fittings are a simple mass-producible grip capable of developing the strength of the rod. The fittings are sized to allow a stress of 100,000 pounds per square inch in the rod before failure of the fitting. The fitting size and rod strength developed were chosen as an optimum balance between maximum strength, insulation length per unit, and economy.

All successful grips for fiberglass rod work by developing high radial force on the rod. This is true with a wedge type, a potted, or a mechanical collet grip. The Hi*Lite grip does away with indirect methods of developing radial pressure. The grip is swaged to the rod with a pressure over 100,000 pounds per square inch on an area of several square inches. The swaging force is controlled to retain totally elastic deformation of the rod under the grip. The resulting attachment is permanent, strong, and reproducible in mass production.

The insulator is rated in terms of "maximum design tension." It is the maximum load the insulator is designed to carry under any conditions without any effect on its life. It occurs at a stress level in the rod of approximately 33,000 pounds per square inch. It is roughly one-tenth the theoretical strength of the fiberglass, one-fifth the average ultimate laboratory strength of the rod, and approximately one-third the estimated average breaking strength of complete insulator assemblies.

The insulators are manufactured in four maximum design tension ratings: 10,000, 20,000, 40,000, and 80,000 pounds. These can generally be equated to the recommended maximum working loads of porcelain insulators.

A 40,000-pound maximum design tension Hi*Lite insulator will be equivalent to two parallel strings of 40,000-pound M&E porcelain suspension insulators. This means a single insulator is available to replace two parallel strings of 40,000-pound M&E suspensions, and a single insulator is also available to replace four parallel strings of 40,000-pound M&E suspension insulators.

The new insulators weigh five to ten per cent of the porcelain insulators they replace.

These suspension insulators are designed to be used in tension. The unloaded leg of a V-string under heavy wind loading will flex in a manner similar to a porcelain insulator string. The Hi*Lite unit will bend and will completely recover when the loading returns to normal.

The light weight of the insulator is especially attractive. A 500-kv phase insulator weighs 40 pounds. A dual string of 40,000-pound M&E rated porcelain insulators required for 765-kv can be replaced with a single insulator weighing only 65 pounds.

The fiberglass core rod consists of glass fibers in a cycloaliphatic epoxy resin matrix. The rod is produced by Ohio Brass. The core rods for the four suspension insulator sizes described are respectively: ⅝, ⅞, 1¼ and 1¾-inch diameter. A 765-kv insulator will use a single 20-foot length of this rod.

The weathersheds protect the rod and provide leakage distance. The size and shape of the sheds give the insulator good performance under contaminated conditions.

The weathersheds are molded as individual pieces. After inspection and testing, they are assembled as a group over the insulator rod. The weathersheds are loaded in axial compression and held compressed by the end fittings. Radial seals between the weathershed and the rod are obtained by stretching them over the rod.

Preloading the skirts in compression utilizes the EPM polymer to provide a live followup for thermal movements of the rod. The polymer can easily follow the elongation of the fiberglass rod under mechanical load conditions.

The weathersheds are not bonded to the rod. They are vacuum assembled to the rod with a silicone dielectric compound filling the interface. The vacuum eliminates air voids which could ionize under sufficient electrical stress. The freedom of movement of the outer covering overcomes inherent problems in the technique of molding skirts directly to the rod and eliminates the problems of differential thermal expansion.

The interface is sealed by five integral O-ring seals per inch of length. The O-ring seals are created by manufacturing the weathershed core diameter smaller than the rod. They are molded into the inner diameter of the EPM polymer weathershed. This divides the interface into dozens of small sealed chambers serving as reservoirs for the dielectric compound. This establishes a labyrinth seal the entire length of the insulator. The redundancy assures freedom from moisture and voids during assembly and prevents entrance of contamination in service.

The compressed live followup from axial compression provides seals between each weathershed. Each weathershed interlocks with the adjacent weathershed. The bottom weathershed interlocks and overlaps the bottom hardware. The top weathershed seals against the top hardware by compression of the material.

If molding defects occur in an individual weathershed it can be rejected without loss of an entire insulator. This is a cost advantage that ultimately benefits the user. The use of many identical small parts assures reliable rapid mass production of the weathersheds.

The end fittings are heat treated and galvanized forged steel. Corrosion problems are minimized by using only two hardware fittings per string. The hardware is well ventilated in service. This improves the life of the galvanized coating. The swaging operation does not damage the galvanizing.

All sizes of Hi*Lite suspension insulators are available with oval-eye end fittings. The 10,000-pound rating is also available with an ANSI class 52-5 ball fitting. The 20,000-pound working load insulator is available with an ANSI 52-8 ball. The ball or oval-eye fitting can be supplied on either or both ends.

There are no American standard ball fittings for insulators of 40,000- or 80,000-pound working load ratings. These are supplied with oval-eye fittings on both ends.

HI*LITE LINE POSTS

The line post insulator is similar in basic construction to the suspension insulators. Its primary service loadings are cantilever rather than tension. A reasonable balance of mechanical characteristics produces a somewhat different design of the main structural members.

The post insulators use a larger diameter core rod. Production of large-diameter high-quality fiberglass rod was a major victory in achieving these designs. For voltages in the 115 and 138-kv and 161-kv range, a 2½-inch-diameter core rod is used. For voltages 161, 230, and 345-kv, a 3½-inch-diameter core rod is required.

Metal end fittings are forged aluminum alloy.

Several design benefits have been incorporated into the Hi*Lite posts. The ability of a fiberglass structure to react elastically under impact loading is a major benefit in the performance of these posts over porcelain posts.

The post mounting base yields under longitudinal overloads before fracture of the rod occurs. The yielding of the metal bases will absorb energy and allow the top of the post to follow the load. Under these conditions a part of the insulator load will be applied as a tension load. Survival of the Hi*Lite post under accidental overload is excellent. When loaded in the vertical direction the bases are rigid up to fiberglass rod fracture.

The posts are rated on the basis of maximum design load. This is the maximum cantilever load the insulator is designed to carry intermittently or continuously with the capability of full recovery. This maximum load must not be exceeded under any predictable loading conditions.

These posts have a usable tension working load of 7,500 pounds. The free-swinging suspension clamp attachment will align itself to apply tension loading in the most efficient manner. The maximum working load in tension can be applied simultaneously with a maximum working load in cantilever.

Running corners with the post loaded in compression may require adapters to allow the clamp full swing clearance toward the post. Special posts can be supplied with rigid conductor attachments for use as jumper loop supports.

The posts have an excellent impact resistance to unexpected overloads due to vehicles striking poles, broken conductors, or other sudden unexpected overloads.

All fittings are sized to allow the rod to develop a maximum fiber stress of 100,000 pounds per square inch.

Posts currently available have maximum working load ratings ranging from 1,100 to 2,000 pounds. (Larger sizes are under development.) The Hi*Lite posts

offer larger cantilever working loads which can be utilized to extend span length or support heavier conductor. These working loads generally exceed the typical working load of ANSI rated 2,800-pound porcelain posts which can be worked to only 1,120 pounds.

The insulators should have an excellent performance in contaminated areas. They have long effective leakage distances and a clean, open design, assuring good natural washing. This should permit line post construction to be extended further into areas of significant contamination.

PROTECTIVE COVERING

The protective covering used on Hi*Lite insulators is identified by the trade name "Dirigo 7000." This is a polymer compound based on EPM which is highly filled and compounded for use as high-voltage insulation. The specific formulations are proprietary to The Ohio Brass Company. The primary constituents are an ethylene propylene copolymer and a hydrated alumina filler.

Weathering resistance is the most important characteristic of all EPM. The principal causes for the weathering of rubber and elastomers are ozone, oxygen, ultraviolet, and water. EPM is virtually immune to ozone and oxygen attack. It is highly resistant to ultraviolet radiation and water. The base material has excellent temperature resistance. It can be used over a temperature range from minus 65 degrees F. to plus 350 degrees F.

EPM is an excellent insulator with high dielectric strength, high track resistance, and high radiation resistance. Dirigo 7000 is in a category of track resistance equaled only by three other known materials: electrical-grade wet-process glazed porcelain, glass, and Dirigo 50 cycloaliphatic epoxy resin. These four materials are comparable in track resistance and exceed by four or five times the next best known materials.

The commonly used sister compound, EPDM, is not as good as EPM in high-voltage insulation characteristics.

All weathersheds for Hi*Lite insulators are manufactured from Dirigo 7000 by special injection molding machines at pressures of 20,000 pounds per square inch. This insures uniformity and freedom from voids.

The basic color of Dirigo 7000 is very close to light gray ANSI 70. Outdoor exposure tends to lighten the color. Indoor storage yellows it slightly. The lighter gray color will return when the material is exposed to ultraviolet.

Chemical resistance of the material is excellent to weak acids, weak bases, alcohols, ozone, oxygen, and detergents. It has good resistance to animal and vegetable oils and fair resistance to petroleum oils and aromatic or chlorinated hydrocarbons. The weathersheds may be cleaned with chlorinated hydrocarbon solvents applied with wiping rags. The material is compatible with silicone oils and entirely unaffected by them even at elevated temperatures.

The performance at higher temperatures than the maximum recommended temperature of 180 degrees Fahrenheit is very good. A six-month baking test at 200 degrees Fahrenheit did no damage. A test at 200 degrees Fahrenheit and 100 per cent humidity for over one year did not damage the weathersheds.

HI*LITE FIBERGLASS ROD

This fiberglass rod, manufactured by The Ohio Brass Company, consists of E-type borosilicate glass fibers impregnated in a cycloaliphatic epoxy resin matrix. The glass fibers constitute over 50 per cent of the cross-sectional area and over 70 per cent of the weight of the rod.

The unique rod manufacturing process results in extreme density and uniformity giving consistent high strength in tension, compression, and flexural loading. Electrical withstand is in excess of 100,000 volts per inch as measured on a full-size specimen by standard 60-Hertz puncture test under oil.

The 100,000-psi strength rating of this rod in tension and compression is conservative. It is based on the practical limits obtainable by conventional means of attachment. Actual strength of the rod is greater but difficult to develop with practical attachment devices.

The rod is manufactured in any length with a current ma: imum of 20 feet consistent with 800-kv suspension insulator requirements. Present production diameters are: ⅝, ⅞, 1¼, 2½, and 3½ inches. Larger diameters or lengths are entirely feasible.

The excellent weather resistance of the rod is typical of epoxy resins. Some degradation of the surface as a result of weathering and ultraviolet exposure can be expected. This is one of the primary reasons for the addition of the EPM weathersheds.

The insulators are manufactured with the glass oriented axially for maximum tensile strength. This does not provide a torsionally rigid unit. However, a four-foot-long piece of the ⅝-inch-diameter rod can be twisted in excess of 180 degrees without damage.

SILICONE DIELECTRIC COMPOUND

The dielectric compound is a very heavy silicone grease especially manufactured for maximum stability and minimum bleed.

A standard acceptance test is a bleed test in which a sample in a cone-shaped screen is held for 24 hours at 390 degrees Fahrenheit. The amount of silicone passing through the screen and collected in a cup is typically 0.02 per cent.

A quantity of grease applied to a short rod on an outdoor test in the Ohio Brass laboratory has not spread onto the adjacent metal end fittings in one and one-half years.

The silicone grease is vacuum processed prior to insulator assembly to prevent possibility of any built-in water or air.

This silicone is far heavier than the typical DC5 insulator grease familiar to most utility men.

END FITTING ATTACHMENTS

A tremendous research effort has evolved the method of attaching end fittings to Hi*Lite suspensions and posts. Many extended series of tests have been run to confirm the integrity of the joint design.

Creep strength tests were run at the extreme load of 100,000 psi (three times the working load) and extrapolated data show load loss on a fixed deflection test of only eight per cent in 20 years.

Thermal cycling is an important consideration. Specimens loaded to 100 per cent of maximum design tension showed no failures on daily thermal cycles from minus 40 Fahrenheit to plus 140 Fahrenheit over a period of four and one-half months. The same test was run at 150 per cent of maximum design tension on the same thermal cycle for one month with no failures.

Fatigue resistance from aeolian vibration is outstanding. Fatigue tests which failed ball-socket suspension insulators in a few hundred cycles did not damage these insulators in six million cycles.

Fatigue tests in bending the rod alone at a stress above the maximum design tension resulted in no failure at 10 million cycles.

Time load tests at 150 per cent of maximum design tension show no failures after five years.

ELECTRICAL CHARACTERISTICS AND TESTS

Conservative interpretation of test data indicates the contamination performance of Hi*Lite insulators is at least 30 per cent better than that of standard porcelain insulators. The small weathershed diameter dries rapidly under leakage currents.

Service conditions can vary widely from controlled laboratory testing; therefore, discretion in application is advised.

DC contamination testing has shown the same level of improvement as for AC.

The Hi*Lite suspension insulator is usually selected on the basis of impulse flashover strength. On this basis the section length is slightly longer than an equivalent string of porcelain suspension units. The additional length is in the axial length of the end attachments.

Extensive puncture tests have been performed. No Hi*Lite insulator has been failed by any test in air. Five insulators were tested by steep wave impulse at a rate of rise exceeding 2000 kv per microsecond for a total of 250 shots with no damage. The most severe test performed was to bolt a unit directly across the end of a five-million-volt impulse generator with no measuring circuit attached. This unit survived 10 shots of each polarity with no damage. The estimated rate of rise was 10,000 kv per microsecond. This test would destroy all weathersheds on glass or porcelain.

Power arc tests have been performed up to 25,000 amperes for six cycles. Several series of these tests, which easily knock the skirts off a porcelain insulator, did not damage the EPM weathersheds. This testing partially melted away the swaged end fittings (they would also melt a suspension insulator cap), but the insulator did not drop mechanical load.

The Hi*Lite suspension insulators are RIV and corona free through 230 kv. The small diameter energized hardware will probably require corona control at 345 kv and definitely require it at 500 kv. Corona control devices can be supplied for these voltages. At higher voltage levels using multiconductor bundles hardware designs can be established to minimize the necessity of separate corona control devices.

RESISTANCE TO GUNSHOT

The brittle material in a porcelain insulator makes it a rewarding target for hunters. The same is true for glass. Summarizing a lengthy laboratory report, the following conclusions have been drawn.

With a 12-gauge shotgun, No. 6 shot, at a distance of 30 to 40 feet, absolutely no structural harm was inflicted on either suspension or posts. A few shot pellets were lightly imbedded in the rubber but none penetrated to any depth.

Several tests were made using 22-caliber long rifle ammunition at the same distance. Examination of the holes showed the disc material had closed behind the shots and only a dimple on the surface revealed the point of impact. There was no other visible indication of a hit. The same ammunition fired directly at the core rod showed a slight scuff on the rod surface but no damage. Some fragments of the slugs were captured between skirt and rod.

High-powered 30-caliber ammunition was fired directly at the Hi*Lite suspension insulator with a ⅝-inch-diameter fiberglass rod (10,000 pounds working load rating). The rod did not completely part. However, a major portion of the fibers was damaged. The insulator was judged to have no remaining mechanical integrity. This bullet was half the diameter of the rod. It passed through the center of the rod. There probably would have been less damage with an off-center hit.

A 40,000-pound suspension insulator was loaded to 28,000 pounds and struck dead center with 30-caliber ammunition. The load on this insulator dropped to 25,500 pounds and held. When the loading was returned to 40,000 pounds, additional fibers broke. Several identical insulators were then subjected to off-center shots. The adjacent weathersheds were often ripped but the insulator showed little loss of mechanical integrity.

A test on a 49-inch horizontal line post produced a dramatic result. This insulator was loaded to 1,100 pounds in cantilever. A 30-caliber shot was then put through the center of the 2½-inch fiberglass rod near the post base. The insulator

did not drop any load. Several additional shots were fired at the same point within a 1-inch-diameter pattern. The post still held load. The load was then increased to 1,500 pounds with no evidence of distress.

These tests show the insulator is immune to shotgun discharges and cannot be mechanically damaged by 22-caliber ammunition. 30-caliber rifle fire striking the exposed disc section of the weathershed is harmless. 30-caliber can inflict structural damage. The amount of damage will depend on whether the impact is a centered or grazing shot.

Rifle fire from a 30-caliber weapon is capable of cutting a conductor or doing major damage to a tower. The Hi*Lite insulator offers a target no larger than the conductor.

To inflict damage, the rod must be struck with high-power rifle fire. The smaller the rod, the greater the damage from a direct hit with 30-caliber ammunition. However, the smaller rod is a more difficult target.

The Hi*Lite insulator is not an attractive target. No chips fly, nothing clinks, and no big pieces disappear. In most cases the shooter does not know if a hit or a miss occurred. The insulator is an extremely unrewarding target because nothing happens.

THOUGHTS FOR THE FUTURE

These lightweight suspension insulators will reduce the number of multiple strings and simplify construction and maintenance techniques.

The lighter weight of the new insulator will reduce many construction problems. Lifting loads at remote work locations are reduced so lighter rigging can be used.

The weight that must be carried with helicopter tower construction will be radically reduced.

The sag introduced by the insulators in spans adjacent to the deadend can be ignored.

Elimination of intermediate hardware joints makes this insulator ideal for lightly loaded situations including jumper supports.

Temporary construction is greatly facilitated.

Handling damage is greatly reduced – fewer trips to deliver material to construction sites.

The Hi*Lite has significant possibilities for application as a mid-span phase spacer.

Diagonal bracing in multiple column structures.

"Catenary" system for three-phase UHV line support – no crossarm.

Longer spans in horizontal post construction (compact lines).

Much greater reliability for horizontal post construction under conditions of gunshot, broken conductor, broken pole, etc.

Horizontal line posts will accommodate larger conductors.

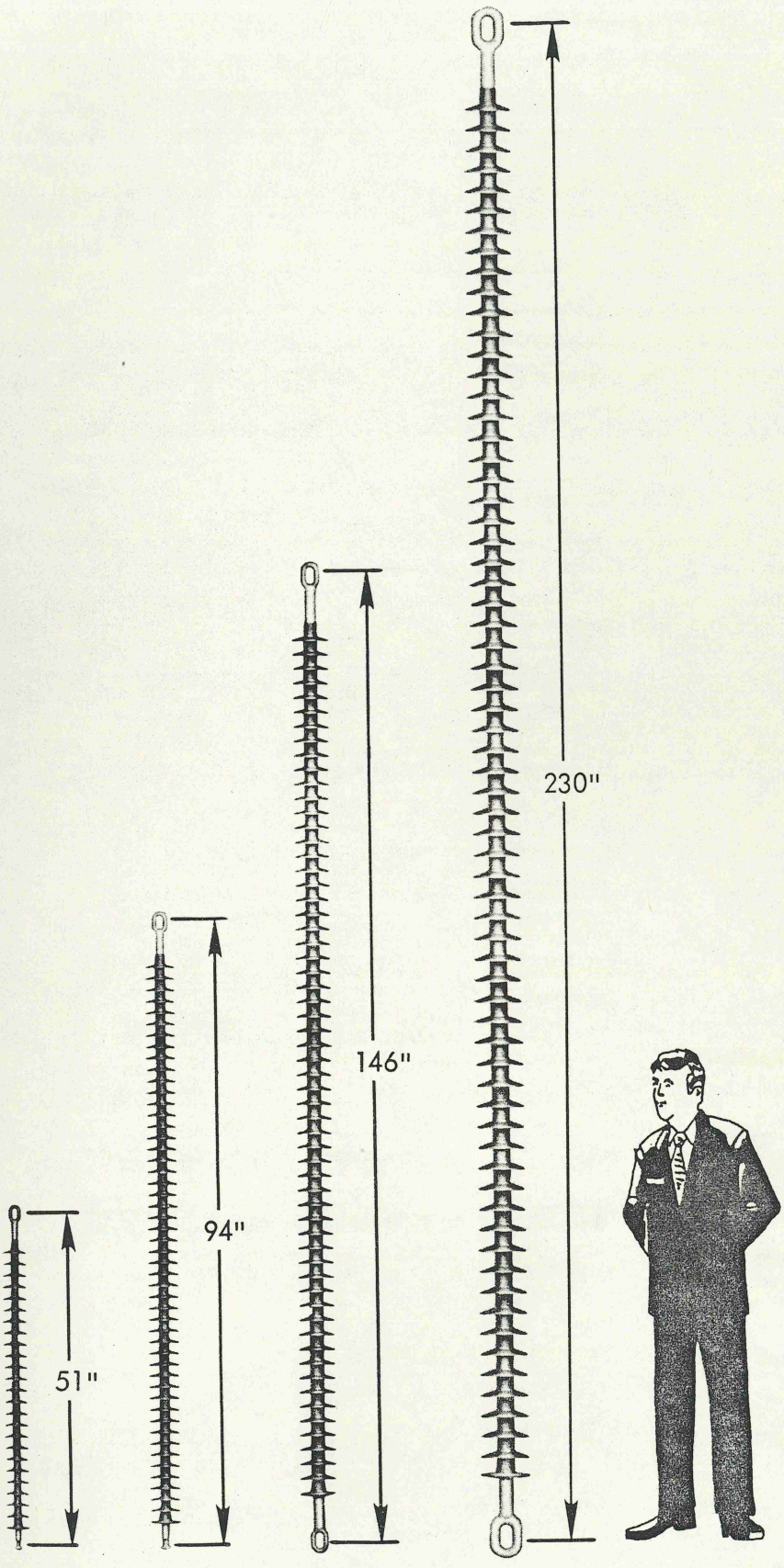
Line post design can be used for 345 kv and 500 kv jumper supports.

CONCLUSION AND SUMMARY

A new high-voltage insulator in both suspension and horizontal line post form is discussed. The insulator design is based on epoxy-fiberglass core rod, EPM polymer weathersheds and swaged-on end fittings. These insulators offer the following outstanding benefits:

- Radically improved strength-to-weight ratio, making the Hi*Lite insulator uniquely adaptable to ultra-high-voltage construction.
- Working strength of single strings of suspension insulators up to three times that of porcelain.
- Confusion of M&E strength ratings eliminated. All published Hi*Lite values stated in terms of maximum working strength.

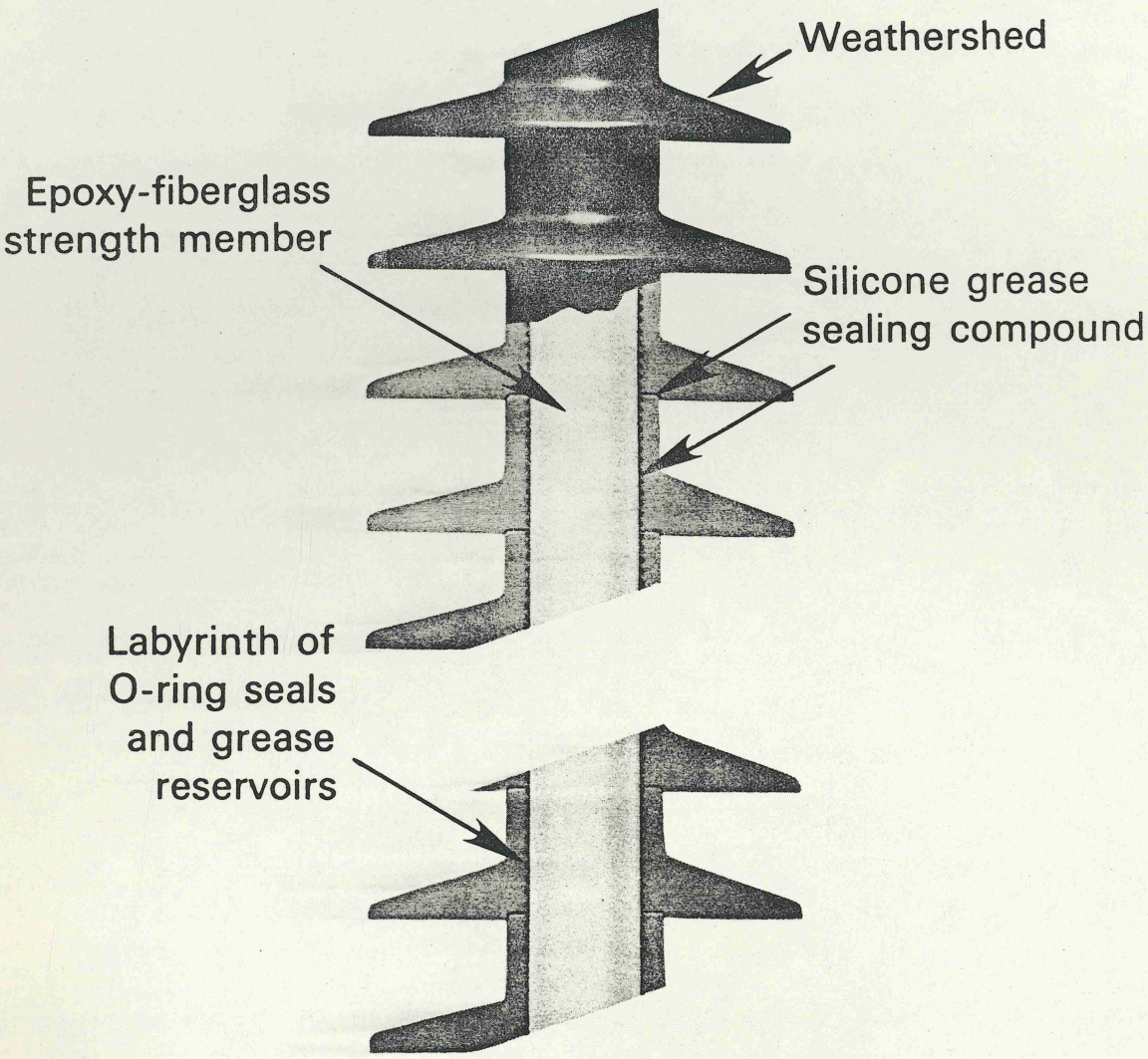
- Tracking resistance approximating glazed porcelain or glass.
- Excellent resistance to all climatic factors.
- Superior to porcelain or glass in resistance to high current or steep wave impulse discharges.
- Immune to electrical puncture.
- Practically unbreakable.
- Highly resistant to gunshot damage.
- Horizontal posts have great adaptation to emergency overloads.
- Failure of a fiberglass strength member is not instantaneous and total. A damaged insulator can often serve until replacement is made.
- Exceptionally good appearance due to slender silhouette.



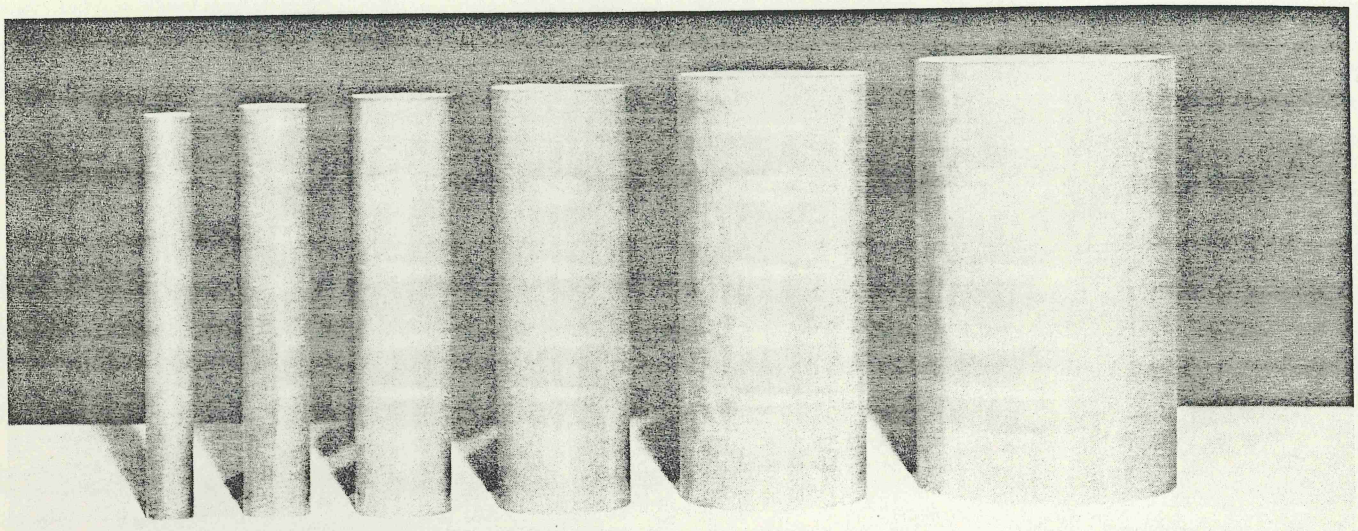
Max. Working Load - Lbs.	10,000	20,000	40,000	80,000
Leakage Distance - In.	110	230	365	580

FOUR STRENGTH CLASSES OF O-B HI-LITE SUSPENSION INSULATORS

TYPICAL UNIT IN EACH CLASS ILLUSTRATED

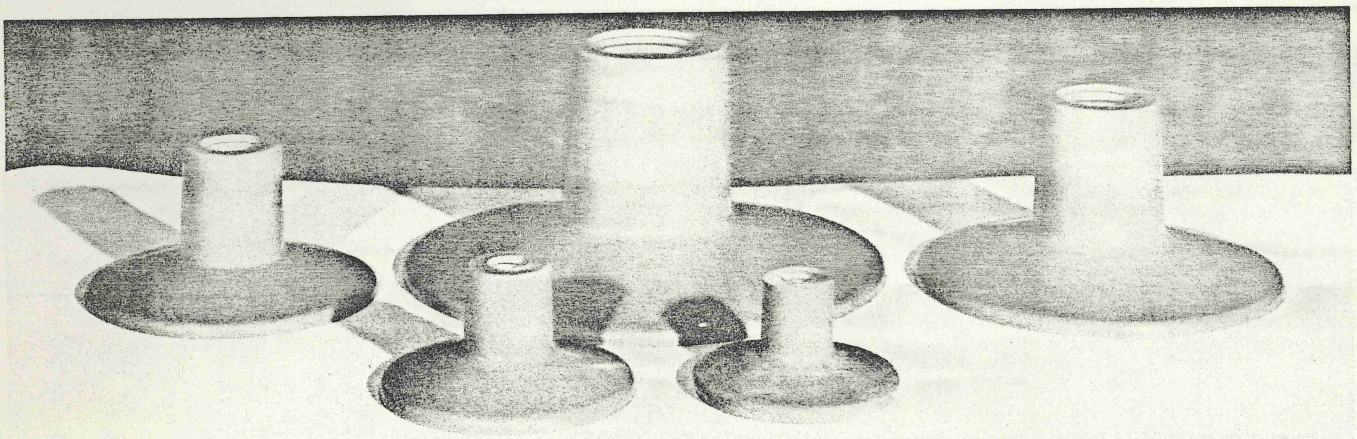


Schematic cross section of Hi-Lite insulator, showing general construction and detail of interface sealing system.

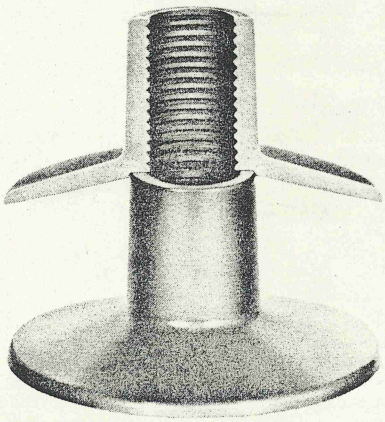


5/8" 7/8" 1 1/4" 1 3/4" 2 1/2" 3 1/2"

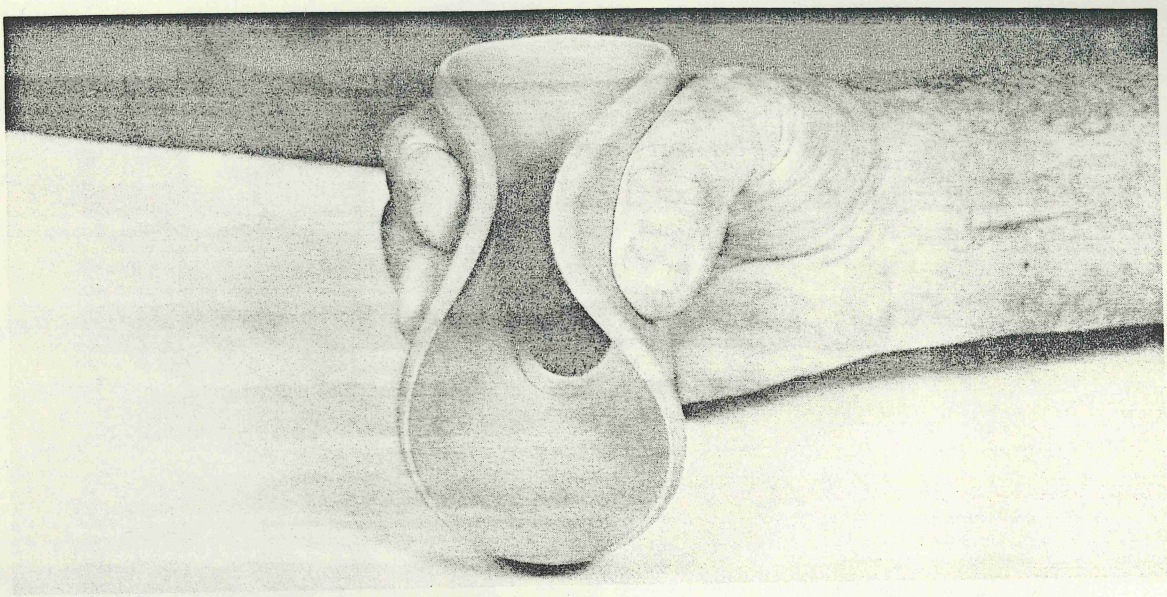
Range of Hi-Lite epoxy-fiberglass rods used in various ratings of suspension insulators and horizontal line posts.



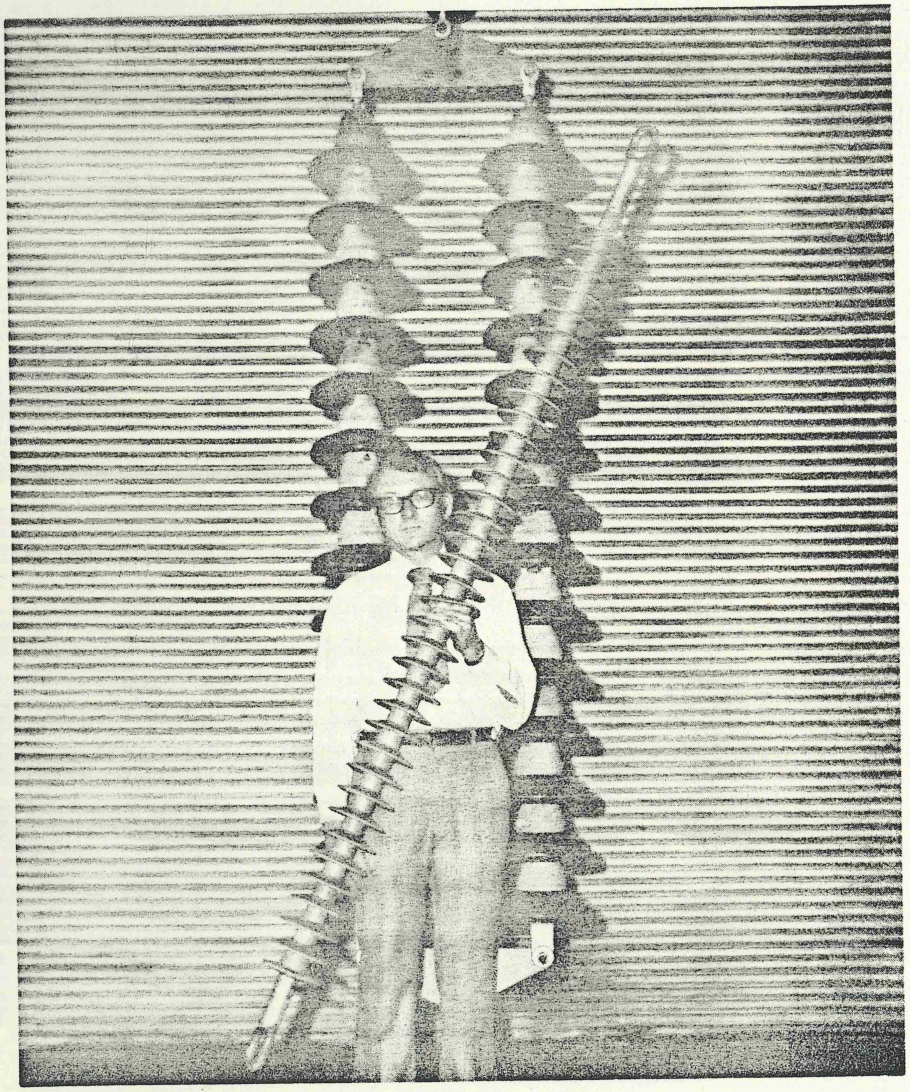
The four smaller weathersheds are those used on the four strength grades of suspension insulators. The large piece in the center is typical of horizontal line post components.



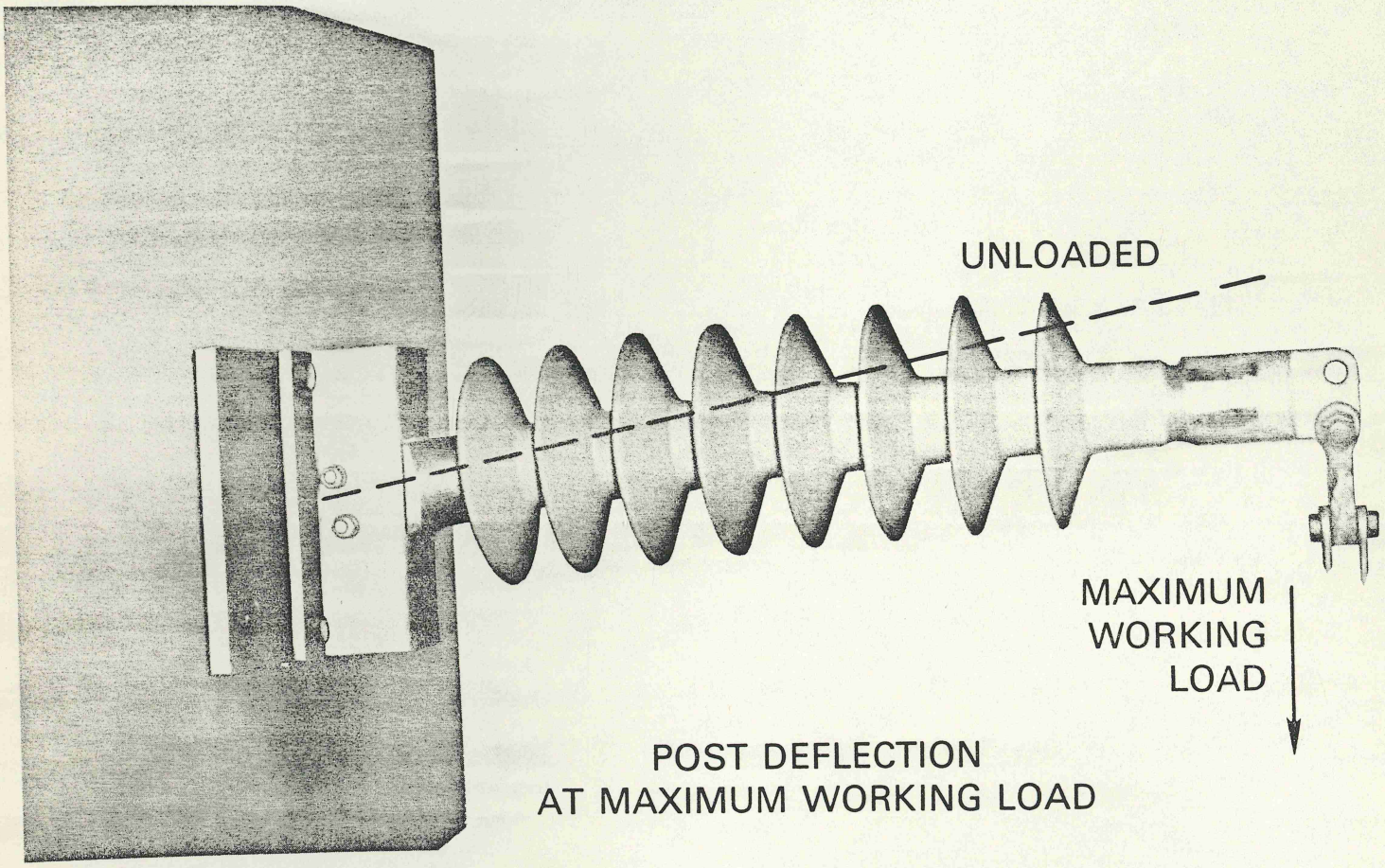
Weathersheds interlock vertically, and the joint is sealed with silicone compound. Assembly is made under axial pressure, utilizing the resiliency of the rubber to maintain a tight joint in spite of slight axial movement of the rod. The labyrinth of O-ring seals is also illustrated.



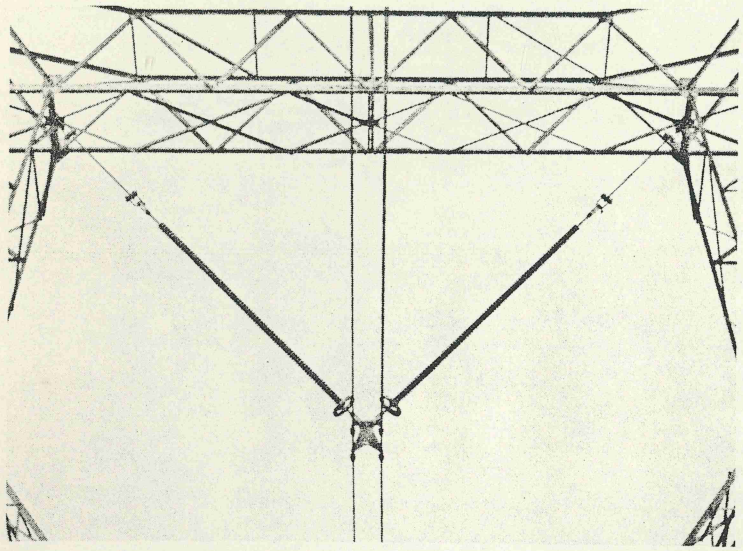
Weathersheds are highly flexible, as this picture demonstrates. Because of this fact Hi-Lite insulators will not be damaged in ordinary handling.



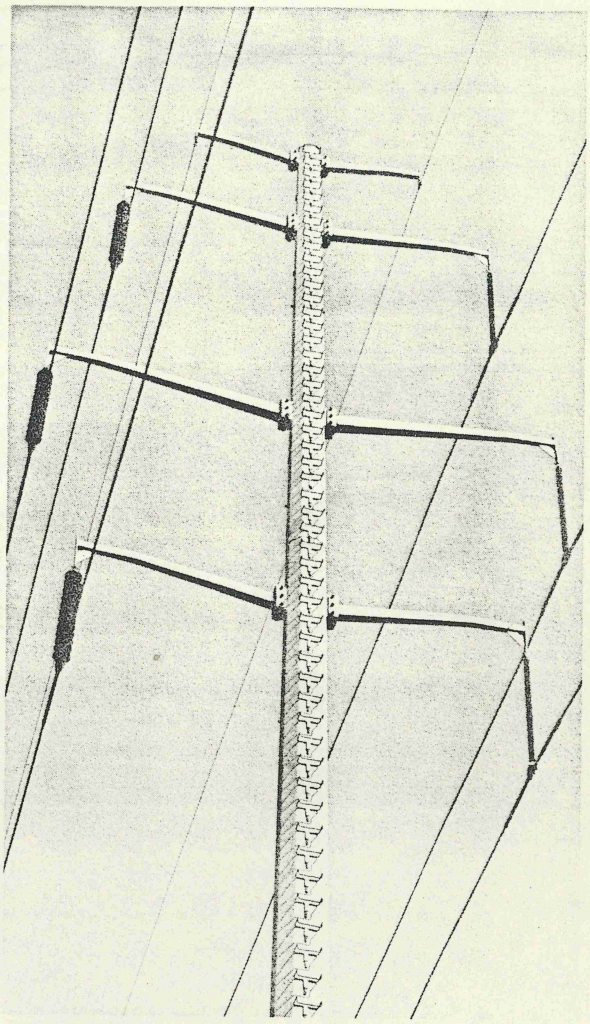
For a working strength of 40,000 pounds in a typical 230-kv application, 36 pounds of Hi-Lite insulator replaces 500 pounds of porcelain.



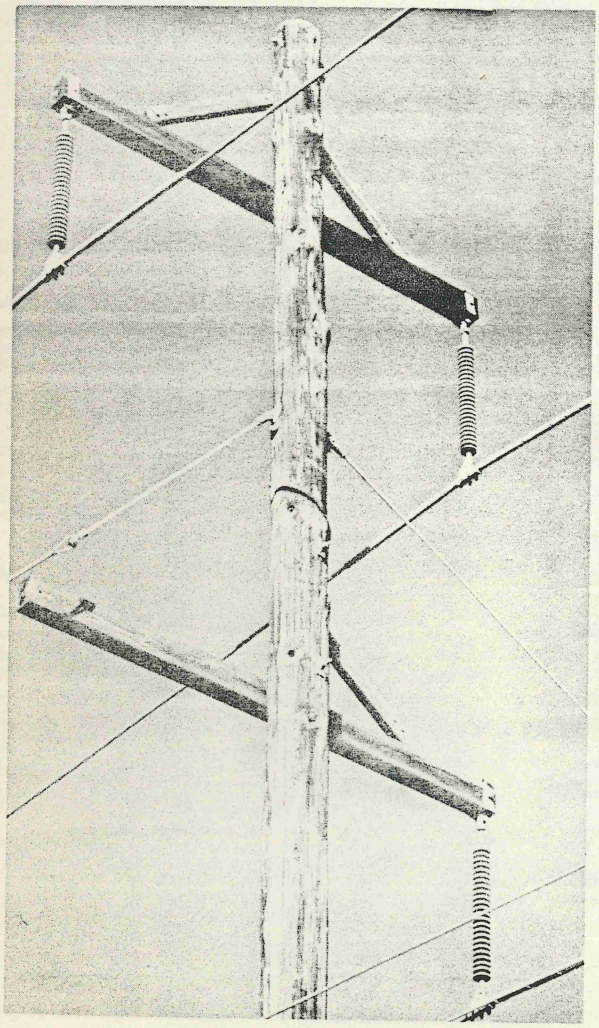
POST DEFLECTION
AT MAXIMUM WORKING LOAD



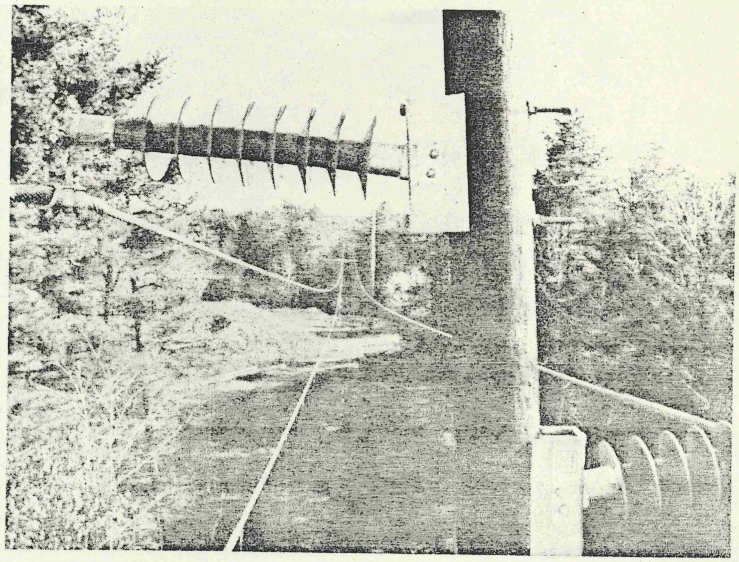
735 kv, Canada, 1975



230 kv, North-Central U. S., 1974



138 kv, Southeast, 1972



138 kv, New York State, Power Technologies, Inc.

Fiberglas does more than replace conventional insulators and crossarms.

It cuts losses from weather and vandals almost 100%.

A strong promise, we'll admit. But according to a manufacturer's tests, Fiberglas*-reinforced plastic really performs.

Fiberglas-reinforced plastic resists gunfire, impact damage and lightning puncture—three major causes of insulator failure.

It also resists the effects of sun, wind, rain, ice storms and snow. Fiberglas-plastic simply won't absorb moisture. Can't rot. And almost never needs maintenance.

What's more, Fiberglas-plastic helps you clean up the skies. The 15KV standoff insulator above, for example, is only 18" long. Much less obtrusive than the standard 8' crossarm it replaces. And the sky-blending grey color is molded right in—not added on.

Weight of the unit above—about 8 pounds. Installation time—about 5 minutes.

And the cost is about what you'd spend for a conventional crossarm with insulators—*initially*. Over the long run, it's actually much less considering the maintenance and replacement costs you avoid.

Want to know who manufactures Fiberglas-plastic standoff insulators? Or more facts about Fiberglas-plastic? Write M. Q. Meeks, Owens-Corning Fiberglas Corporation, Fiberglas Tower, Toledo, Ohio 43659.

*T.M. Reg. O.-C.F.

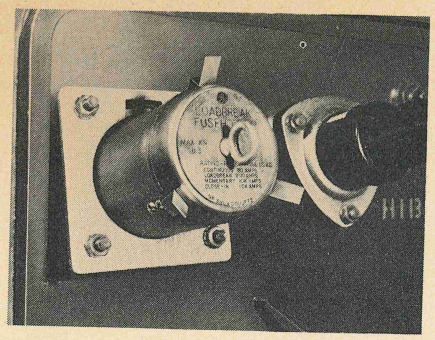
Owens-Corning is Fiberglas

OWENS/CORNING FIBERGLAS TRADEMARK®

Inquire T&D 9332

Dry-Well, C-L Fuse Holder

Fuse holders that combine the high interrupting capability of general-purpose current-limiting fusing with a new air-insulated dry well holder have been placed on the market for application on single- and three-phase pad-mounted transformers. The fuse holder unit, which is mounted into the transformer tank below oil level, allows easy external replacement of the current-limiting fuse. Two types of dry well fuse holders are available: nonload-break and load-break. The nonload-break unit is available at 21.1 kv and below and 125-kv BIL and below. This type incorporates a plate that warns against operations while the transformer is energized, plus a safety



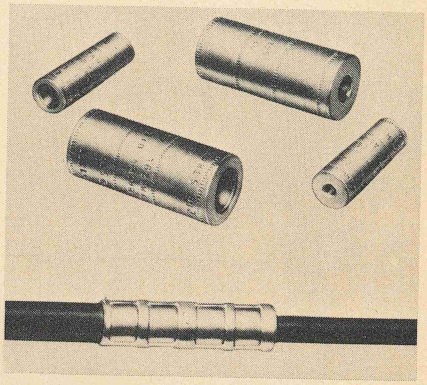
baffle which must be removed before gaining access to the fuse. The second type of fuse holder (illustrated) functions as both the dry well and load-break switch. Switching is by the rod-and-bore principle. Arc quenching is achieved by an epoxy having properties that maximize the number of switching operations and provide excellent thermal stability. The load-break fuse holder is currently available at 8.3 kv, 95-kv BIL. Momentary rating is 10,000 amps, rms symmetrical.

General Electric Co., One River Rd., Schenectady, N.Y. 12305.

Inquire T&D 1857

Splice for Different Sized Cable

Hyreducer compression reducing splice, specially designed to join different cable sizes, is UL-listed for aluminum and aluminum-to-copper connections. Filled with Penetrox electrical joint compound at the factory, the product features a solid



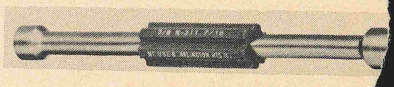
center barrier that assures proper insertion of cable and thorough penetration of the compound between conductor strands. The splice is clearly marked for catalog number, wire size and type, die index and color coded for identification. It is also knurled for proper number and location of crimps. Its smooth profile results in easy taping. The splice is available in cable sizes from 6 st through 750 MCM.

Burndy Corp., Norwalk, Con 06852.

Inquire T&D 1858

Electronics Communications Too

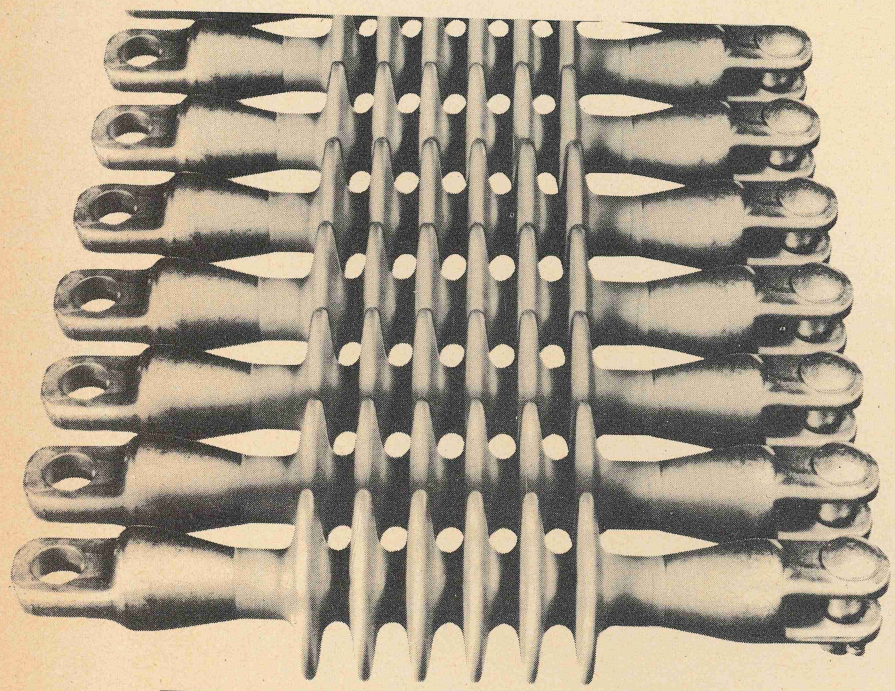
Design of the N-311 hex sock wrench meets Telco standards f hex nuts and bolt heads. End sha of the tool are hollow so nuts a long screws can be reached with



difficulty. The handle, with onl 11/16th-inch O.D., allows the us reach into narrow openings. Sinc handle is 2 inches long, only tip pressure is exerted.

P.K. Neuses, Inc., Box 10 lington Heights, Ill. 60006.

Inquire T&D 1859



REZLINE™

"the people pleasers"

REZLINE Suspension Insulators, from Permali, Inc., combine light weight, compact/one-piece design, high impact strength, self-cleaning properties, trim/uncluttered styling, minimized radio and TV interference—even special package design reducing storage area requirements. With all this going for them, it's no wonder REZLINE Insulators are pleasing just about everyone: utility managers, linemen, storekeepers and the *community!* □ Available in 15, 25 and 34.5 kV sizes for all horizontal applications, REZLINE's epoxy skirts, fiberglass rod and forged aluminum end fittings (malleable iron on 34.5 kV size) deliver a unit 80% lighter than porcelain. □ Send for the literature. □ Permali, Inc., Mount Pleasant, PA 15666. West Coast: Permali Pacific, Inc., 10930—116th Ave. NE, Kirkland, WA 98033. Canada: Permali (Canada) Ltd., 2870 Slough St., Malton, Ontario.

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Inquire T&D 1856

A HIGHLINE Fiberglass Pole Top Extension...total weight 75 lbs...total cost including installation under $200...and the unit is stronger than the pole itself...

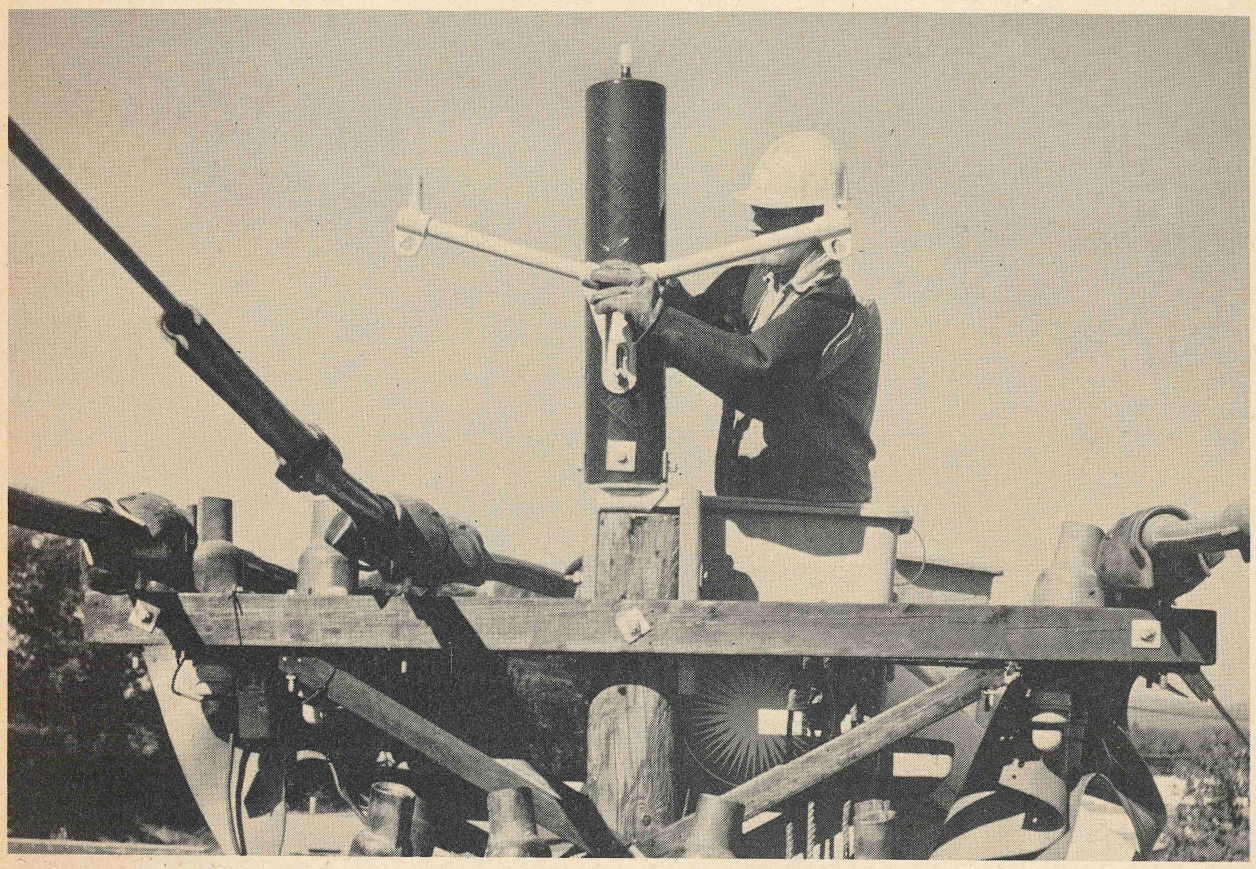
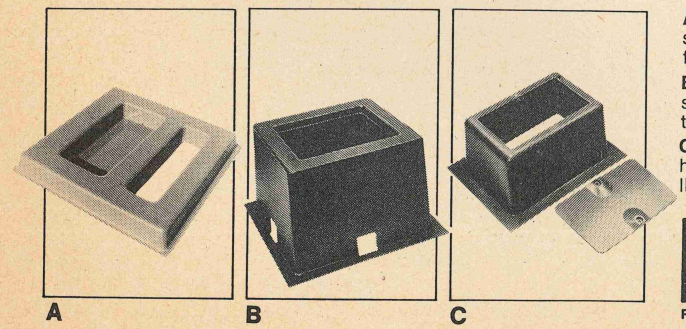


Photo shows unit capable of accepting poles of 21" - 31" circumference. Larger units are available.

HIGHLINE Fiberglass Pole Top Extensions are real time and money savers. One user saved more than $100,000 in their first year of use.

When it is necessary to add an additional 3 phase circuit on an existing pole having cable terminators, transformers or other equipment attached, it is not unusual to achieve a saving up to $1200 by the use of a pole top extension. For more detailed information write for an HL-44 brochure. Shown below are three of the many other Highline quality products.



A B C

A. The HL-46 Transformer Pad is matched die molded of light, strong fiberglass reinforced polyester which retains full strength from deep winter cold to temperatures in excess of 350°.

B. A Highline Fiberglass Box Pad gives you four times the strength required and cuts installation costs by as much as one third.

C. The HL-41 Fiberglass Secondary Splice Box is unaffected by heat or cold, has an ultimate vertical load capability of 4,000 lbs and a sideload capability of 3,000 lbs.

HIGHLINE
PRODUCTS CORPORATION

299 Riverside Ave.,
Westport, Conn. 06880
Phone (203) 227-4111

Inquire T&D 1923

T&D MEETINGS

September 10-13 — Western Electronic Show & Convention (WESCON), Los Angeles, Calif.

September 16-17 — NELPA Annual Meeting, Northern Hotel, Billings, Mont.

September 18-20 — Municipal Electric Utilities Assn. of New York Annual Conference, Lake Placid Club, Lake Placid, N.Y.

September 20-21 — 56th Public Utilities Assn. of the Virginias Annual Meeting, White Sulphur Springs, W. Va.

September 23-25 — TVPPA Engineering, Operations and Safety Sections Conference, Vanderbilt Holiday Inn, Nashville, Tenn.

September 24-28 — Ninth World Energy Conference, Detroit, Mich.

September 26–27 — Transmission & Substation Symposium, University of Texas. Arlington, Texas

September 30-October 4 — NWPPA Underground Distribution School, Holiday Inn, Everett, Wash.

October 3-4 — EEI T&D Committee Meeting, Olympic Hotel, Seattle, Wash.

October 8-9 — PEA T&D Committee Meeting, Venice Motel, Hagerstown, Md.

October 10-11 — PEA Meter Committee Meeting, Seven Springs Resort, Champion, Pa.

October 21-22 — Midwest Power Symposium, University of Missouri, Rolla, Mo.

October 21-23 — 27th Annual Power Distribution Conference, University of Texas, Austin, Texas

October 24–25 — PEA Communications Committee Meeting, Bell Laboratories, Holmdel, N.J.

October 27-31 — NECA National Convention, San Francisco, Calif.

November 7-8 — IEEE Canadian Conference on Communications and Power, Queen Elizabeth Hotel, Montreal, Canada

November 11–13 — 48th Annual NEMA Meeting, Hyatt Regency O'Hare, Chicago, Ill.

December 2–4 — IEEE National Telecommunications Conference, Sheraton Harbor Island Hotel, San Diego, Calif.

January 16-17, 1975 — EEI T&D Committee Meeting, Hotel Westward Ho, Phoenix, Ariz.

January 19-23 — NRECA Annual Meeting, New Orleans, La.

January 21-22 — 25th IEEE Vehicular Technology Conference, Royal York Hotel, Toronto, Ontario, Canada.

January 27-February 1 — IEEE Power Engineering Society Winter Meeting, Statler Hilton Hotel, New York, N.Y.

February 9-14 — Construction Equipment Exposition & Road Show (CONEXPO '75), McCormick Place, Chicago, Ill.

February 24-25 — EEI System Planning Committee Meeting, Marriott Hotel, New Orleans, La.

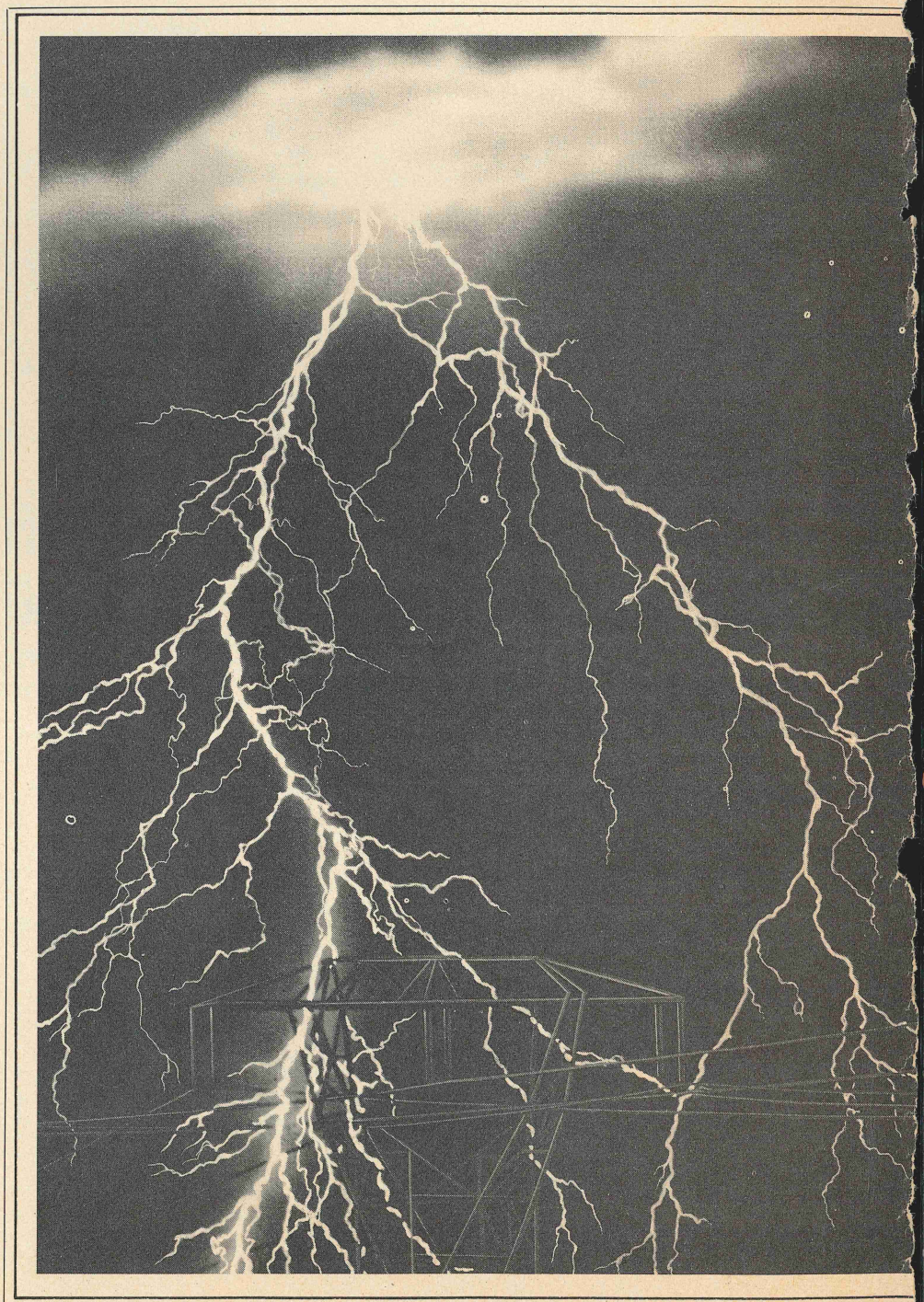
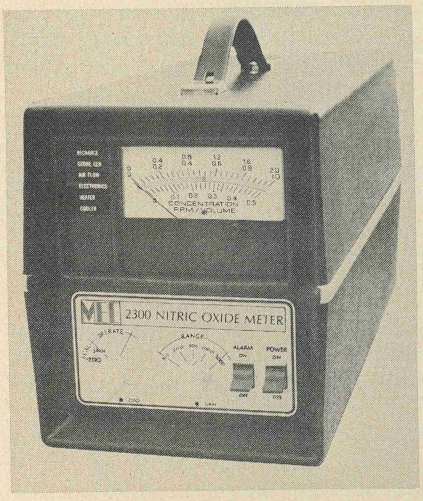


photo) rated 10 to 50 kva. The single-phase unit is a deadfront, loadbreak economy transformer, also available in loop or radial feed. Externally clamped bushings can be replaced if damaged.

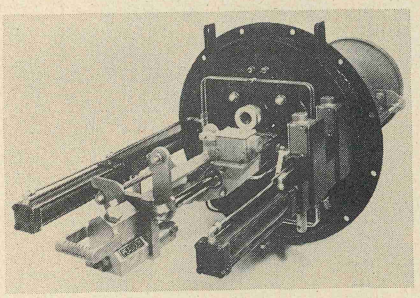
READER SERVICE CARD NO. 305



NO meter

McMillan Electronics Corp, Houston, Tex., has introduced Model 2300 portable NO meter. The 12-lb unit measures NO levels with a precision of ±1% of full scale. The 2300 uses the chemiluminescent detection principle and covers source and emission ranges for NO of 0-100, 0-200, 0-500, 0-1,000, and 0-2,000 ppm. Each model has an audible adjustable automatic alarm system and outputs for recording. The meter features an automatic failure-diagnostic system, which displays a malfunction to minimize servicing and troubleshooting.

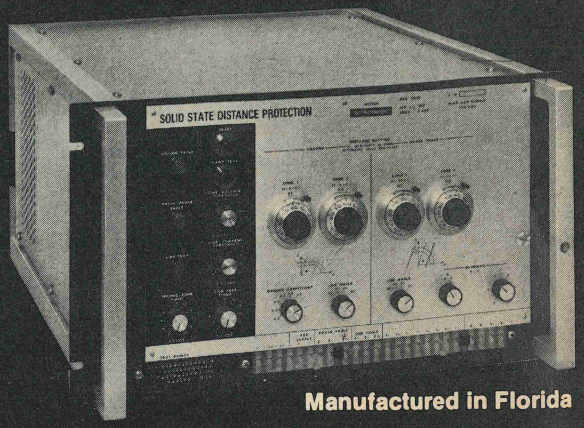
READER SERVICE CARD NO. 306



Burner

Peabody Engineering Corp, Stamford, Conn., has introduced a clean-firing burner for utilities, package boilers, and large industrial power plants that eliminates the need for particulate-removal equipment. The air-pressure recovery (APR) burner keeps emissions within EPA limits of 0.1 lb/MMBtu when firing 0.1%-ash fuel oil. It operates down to 2% excess air and reportedly improves boiler efficiency and conserves

7 reasons why WESTON Distance Relays are different



Manufactured in Florida

1 **Solid-State design with isolated inputs and outputs.**

2 **Comparably priced to electro-mechanical relays.**

3 **Small, single package design . . . our 10½ inch rack mount case reduces installation costs.**

4 **Two zone design for phase and ground protection.**

5 **Plug-in DC to DC converter.**

6 **Ten independent output function contacts.**

7 **Carrier or straight distance relaying.**

Hundreds of Schlumberger Distance Relays are now in operation throughout the world . . . protecting high voltage lines from 69kV to 500kV.

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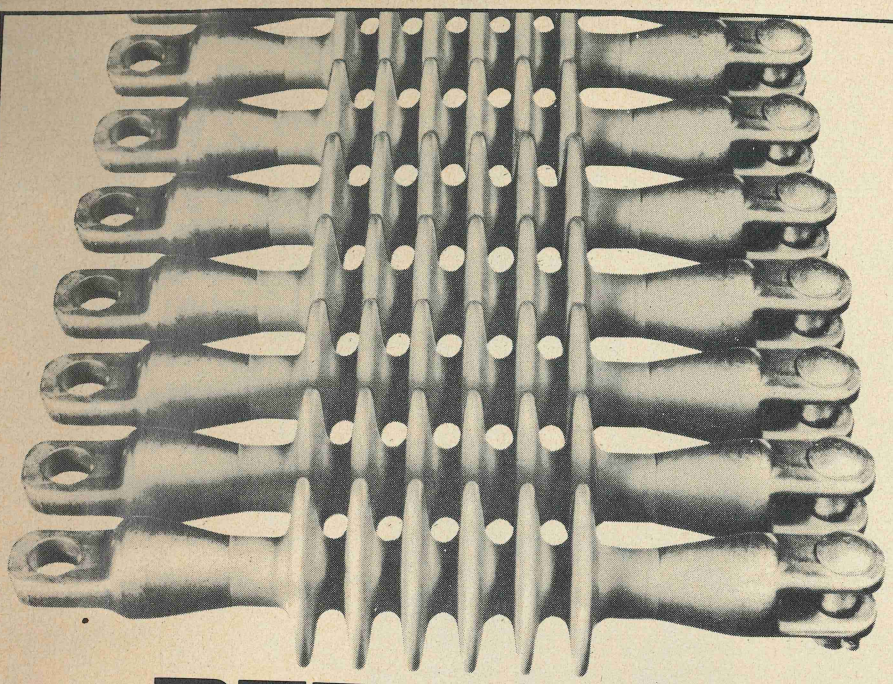

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ABOUT YOUR SUBSCRIPTION

Your subscription is maintained on one of the world's most modern, efficient computer systems, and if you're like 99% of our subscribers, you'll never have any reason to complain about your subscription service.

We have found that when complaints do arise, the majority of them occur because people have written their names or addresses differently at different times. For example, if your subscription were listed under "William Jones, Cedar Lane, Middletown, Arizona." and you were to renew it as "Bill Jones, Cedar Lane, Middletown, Arizona," our computer would think that two separate subscriptions were involved, and it would start sending you two copies. Minor differences in addresses can also lead to difficulties. For example, to the computer, 100 Second St. is not the same as 100 2nd St.

So, please, when you write us about your subscription, be sure to enclose the mailing label from the cover of the magazine - or else copy your name, address and identity code exactly as they appear on the mailing label. This will greatly reduce any chance of error, and we will be able to service your request much more quickly.

fuel. When steam atomization is used, low steam consumption of about 0.04 lb of steam per lb of oil also contributes to energy savings. When mechanical atomization is used, maintenance is reduced with the APR burner because of a tip seal in the oil gun. This allows burner shutdown without retraction of the oil gun. Circulated oil cools the tip, eliminating carbonization, tip plugging, and the need for purging the atomizer. A venturi-form air register provides low air velocity at the entry and low overall pressure drop. Air entering the register is divided into two streams by a splitter plate to ensure that air breakaway is avoided without employing air swirl. The burner is designed for pressurized or balanced-draft furnaces and can be used with high-temperature combustion air. Complete combustion is promoted by controlled primary and secondary air flow and wide-range oil-atomizing systems. APR burners are available in capacities from 1,550 to 15,000 lb/hr (about 300-million Btu/hr) for oil, gas, or oil/gas-combination firing. There are no moving air doors; the burners have a two-position (open/shut), pneumatically operated slide to shut off air supply to idle burners. Peabody Engineering also supplies auxilliary equipment for the burner, including ignitors, flame safety controls, burner-management systems, and fuel-preparation sets.

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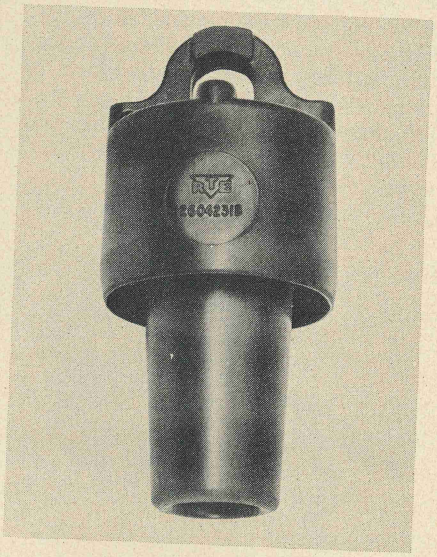
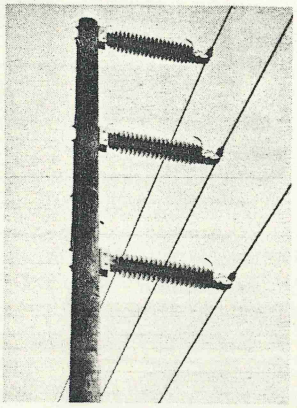


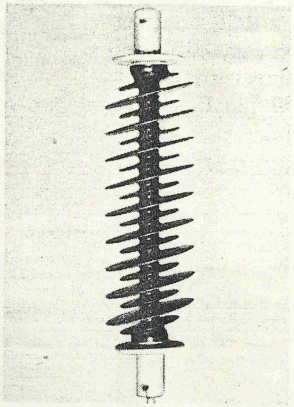
Bushing-well plug

RTE Corp, Waukesha, Wis., has introduced a single bushing-well plug that replaces the bushing insert and cap. The plug, which screws into an 8.3- or 15.2-kv well, seals and shields unused bushing wells. Complete moisture sealing and dielectric interface integrity are achieved by interference fit of EPDM insulating rubber with the premolded bushing-well interface. A 100-mil-thick molded semiconductive shield with

You've got porcelain/glass transmission insulator problems: Weight, breakage, strength, R.I.V., contamination, appearance, etc., etc...

We've got "The Alternative":





TDL™ Polymer Insulators.

You and your utility probably face most—or all—of the porcelain/glass transmission insulator problems above . . . as well as many others including unsatisfactory dynamic loading performance, marginal low temperature strength, and mechanical failure due to power arcs.

Now is the time to consider "The Alternative": TDL Polymer Insulators—in both suspension/tension and line post designs—with nearly a decade of successful on-line performance.

The TDL high strength, high dielectric epoxy-fiberglass core offers suspension M&E ratings to 120,000 pounds and line post cantilever strengths to 5500 pounds, while displaying excellent dynamic loading performance—no collapsible bases or conductor clamp shear pins are required. At extremely low temperatures porcelain becomes hazardously brittle; however, the tensile modulus of the TDL core increases only slightly, thus minimizing the possibility of failure.

End fittings on TDL units are designed to keep power arcs away from the core and thus prevent mechanical failure during flashover. In addition, erosion of the insulator surface during power arcs is limited to the outer edges of the epoxy sheds, and there is no interspersed metalwork to draw an arc close to the insulator surface. The elimination of connective metalwork interfaces also prevents R.I.V. generation resulting from puncture of oxide films by leakage currents.

The TDL patented, angled-shed design permits natural washing over the entire leakage path, not just the upper surfaces of the sheds. Combined with a 4.5-to-1 leakage path-to-overall-length ratio, TDL Insulators exhibit superior anticontamination properties.

Additionally, the slim, unobtrusive TDL profile displays concern for environmental aesthetics.

TDL insulators are available in all transmission voltage classes—from 69kV through 1100kV.

Significantly lighter and easier to handle than their porcelain and glass counterparts, one-piece TDL insulators offer cost savings through simplified installation, and reduced system maintenance due to extremely high impact strength as well as their proven self-cleaning properties. While the initial purchase price of TDL insulators at lower transmission voltages is comparatively greater than that for insulators of conventional materials, costs for high strength *EHV* class units offer savings at the *time of purchase.* In addition, at *all* voltage levels, there are installation, handling and breakage savings, as well as reduced long-term maintenance costs.

☐ For full technical data, and information on the significant economies of uprating and new construction with the TDL "Alternative," call or write Transmission Developments Division of Permali, Inc., Mount Pleasant, PA 15666, 412/547-5732. West Coast: Permali Pacific, Inc., 10930—116th Ave., N.E., Kirkland, WA 98033, 206/822-0217. Canada: Permali (Canada) Limited, 2870 Slough St., Mississauga, Ontario, L4T 1G3, 416/677-2090.

PERMALI

Transmission Developments Division of Permali, Inc.

Inquire T&D 3749

IREQ
Institut de recherche
de l'Hydro-Québec
1800, montée Sainte-Julie
Varennes, Québec, Canada

R. Keller
Note "X" on next to last Page.
This will be a very sticky area
for us.
BSK 10/9

October 1st, 1975.

Members
WG on Testing and Application of Non-Ceramic Insulators

Gentlemen:

I am enclosing a draft of the minutes of our recent meeting. It is important that any errors or omissions should be reported to me within 3 weeks of receipt of the draft.

Yours sincerely,

G. Karady

DR. G. KARADY
Chairman of the WG

(encl)

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OCT 0 1975

MINUTES

W.G. on testing and application of Non-Ceramic Insulators.

Date: July 24, 1975.

Location: San Francisco Hilton, S.P.

Present:	Name	Affiliation
	Peter Ralston	Ontario Hydro
	Roy Broad	Raychem
	Roy Gladwell	Dunlop
	Stewart Knudsen	Pacific Gas & Elect.
	Fernand Couquelet	Sediver Inc.
	Michel Willem	Ceraver
	Gary Stemler	Bonneville Power Admin.
	Kirby C. Holte	Southern Calif. Edison
	Wm. Nelson Jensen	Balto. Gas & Elec.
	W.R. Stephens	Sverdrur & Parcel
	Roy E. Meyer	Meyer Ind.
	Jack Reichman	Ontario Hydro
	Stig Annestrand	BPA
	Doug Young	Canadian Porcelain
	Herman Schneider	Proj. UHV- Gen.Elec.
	D.E. Winters	Ohio Brass Co.
	A.G. Yost	Ohio Brass
	G.E. Lusk	Joslyn Mfg. & Supply
	J.H. Moran	Lapp Insulator Div.
	S.S- Low	La. Dept. of Water & Power
	B.E. Kingsbury	Locke Insulators
	E.A. Bauer	Rosenthal Technic
	W.T. Starr	Raychem
	J.F. Moran	Pacific Gas & Elec.

The purpose of the first meeting was to discuss the name and scope of the WG. Before proceeding with this task the members persent, introduced themselves and outlined their activity and interest in the subject.

The present activity on new types of insulators can be summarized as follows:

Ontario-Hydro: (P. Ralston, J. Reichman) reported tests on phase spacers, made out of synthetic materials; which will be used for upgrading 150 kV transmission lines. Ontario-Hydro is engaged in systematic testing of these new insulators (contamination, icing tests, etc.).

Project UHV - General Electric: (H. Schneider) reported on contamination and icing tests and stated that synthetic insulators are used on their 1500kV three-phase test line.

Raychem, Menlo Park: (R. Broad and W.T. Starr) as an insulator material manufacturer reported tests on materials.

Dunlop, Crofton, MD: (R. Gladwell) manufacturer reported preliminary work on synthetic insulators.

Pacific Gas and Electric: (S. Knudsen, J.F. Moran) reported several years of field testing of synthetic insulators at the Mos Landing station (one type of insulator has been exposed for 1 year, the other has already been under test for 2 years). The testing of these insulators in a fog chamber is under preparation.

CERAVER, France and SEDIVER (N.J.) (Mr. M. Willem, F. Couquelet) reported that a new high-strength non glass composite insulator is under development and test in France.

Bonneville Power Administration: (S. Annestrand, G. Stemler) reported that the BPA has installed limited numbers of synthetic insulators on the 150 kV network and forsees their use as dead-end insulators on the 1200 kV line. It is planned that other insulators on this line will be replaced by plastic insulators.

Southern California Edison Co.: (K.C. Holte) reported on extensive outdoor tests of different non ceramic insulators conducted during the past few years, on material tests on small samples, and on studies of the aging mechanism.

Balto Gas and Electric: (W.N. Jensen) in 1959 several new types of insulators were installed in a horizontal position on a dead-end structure of a 150 kV line. Six of them failed after 7-8 years. Foreign-built insulators are also under test on 230 kV and 115 kV lines.

Ohio Brass: (D. Winters, A.E. Yost) reported on the development of synthetic insulators resulting from 12 years of research work.

Joslyn Mfg. and Supply: (Dr. G.E. Lusk) reported on development work on composite insulators.

Lapp Manufacturer: (J. Moran) expressed interest and reported on certain development work.

L.A. Department of Water and Power: (S. Low) reported that new composite insulators have been installed on a 400 kV dc line operating under conditions of heavy contamination for a year. Field tests are in progress on 230, 287 and 137 kV transmission lines.

Rosenthal Technik: (Dr. E.A. Bauer) reported on 11 years of research work and development of synthetic insulators. About 6,000 units; have seen delivered to several utilities in Europe Some of them have been in service for 8 years.

The name of the WG was discussed in detail and it was agreed that the name of the working group will be: "Testing and application of non-ceramic and composite insulators for transmission lines". As an afterthought the chairman believes that this title is too long and suggests shortening it to: WG on: "Non-ceramic and composite insulators for transmission lines".

The opinion of the members are requested.

The scope of the WG, as well as the work program were discussed. The main points of the discussion are as follows:

Dr. Lusk raised the question of whether or not the insulators for substations are to be included. The majority of the members felt that the WG should deal with transmission line insulators only.

Dr. Schneider suggested comparing of laboratory tests with field experiments. The laboratory tests should be related to the service conditions.

Dr. Bauer suggested developing a specification and basic test program, which would eliminate improperly manufactured, low quality insulators from the market because it is very easy to use unsuitable plastic for making synthetic insulators which look like good insulators. The failure of these insulators in service would delay the application of composite insulators. A basic test program would protect the composite insulators and ensure a minimum quality requirement. This idea was supported by Dr. Lusk, Mr. Winters, and Mr. Wille .

Mr. Starr emphasized the importance of weathering problems and explained that an IEEE WG deals with these problems in connection with polymer cable terminations. It was felt that collaboration between the two WGs would be very desirable and the chairman asked Mr. Starr help in developing this collaboration and to obtain documents on the work of the other WG.

Mr. Ralston suggested that before establishing the test program the requirements and specifications would have to be discussed. This view was supported by Mr. Stephens and Mr. Meyer, and Dr. Holte.

Mr. Willem, Mr. Couqualet and Dr. Schneider emphasized the importance of combined-thermal and mechanical tests together with a study of the effects of UV light and humidity.

Mr. Jensen talked about impulse level and testing problems.

Mr. Annestrand suggested exchanging the results of field experience, in order to help in determining the present state of the art.

Dr. Schneider and Mr. Stemler suggested that the WG should discuss ratings, specifications and required safety factors for non ceramic insulators, of particular importance are the mechanical characteristics.

Dr. Holte, Dr. Lusk, Dr. Bauer, Mr. Ralston and Mr. Yost discussed the problem of comparing the test results obtained by different laboratories and utilities.

It was felt that due to the propriatary nature of the results, the WG will concentrate on specifications and testing methods. It can be foreseen, however, that a certain exchange of test results (with the permission of all the interested parties) will take place in the WG at a later time.

Mr. Starr pointed out the importance of the UV radiation test. It is possible to destroy an insulator by UV radiation. Accelerated life tests, which simulate 30 years of life, were developed.

Mr. Yost emphasized that the WG should concentrate on test methods and any kind of advertisement should be avoided.

Finally it was agreed that: 1) on the basis of the discussion the chairman will prepare the "Scope" of the WG and submit it for the next meeting.

2) The manufacturers will prepare a 10 minute presentation for the next meeting about the stage of development of synthetic insulators. The presentation should be technical in nature and without any advertisement. The purpose of the presentations is to determine the present state of the art in the point of the manufacturers.

The manufacturers are asked to indicate to the chairman their intention to prepare the requested state-of-the-art presentation for the next meeting.

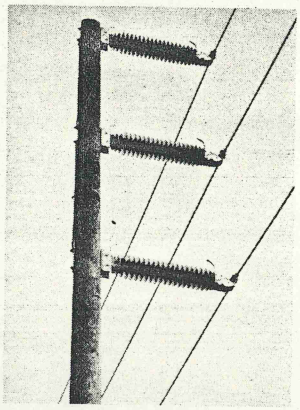
WORKING GROUP ON

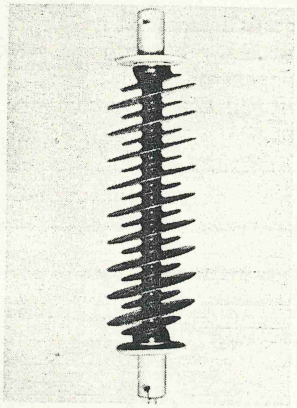
NON-CERAMIC AND COMPOSITE INSULATORS FOR TRANSMISSION LINES
(IEEE Lighting and distribution Subcommittee).

Scope. Treatment of all the problems connected with the application and field and laboratory testing of non-ceramic and composite insulators for transmission lines. Particular attention will be given to the problem of specifications, rating, and the testing techniques. Furthermore the advantages and disadvantages of these new types of insulators, together with the possible fields of application, will be discussed.

You've got porcelain/glass transmission insulator problems: Weight, breakage, strength, R.I.V., contamination, appearance, etc., etc...

We've got "The Alternative"!





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PERMALI

Transmission Developments Division of Permali, Inc.

Inquire T&D 3749

NGK INSULATORS, LTD.

MAIN OFFICE
CABLE : NGKINSULATOR
NAGOYA
TELEX : NGK J59928

TOKYO OFFICE
NO. 20 MORI BLDG.
NISHISHINBASHI 2-CHOME
MINATOKU, TOKYO, JAPAN
CABLE : NGKINSULATOR
TOKYO
TELEX : NGKTOK J24250

MIZUHO, NAGOYA, JAPAN.

December 17, 1975

Mr. B.E. Kingsbury
Vice President-Engineering
LOCKE INSULATORS, INC.
2525 Insulator Drive
Baltimore, Maryland 21230
U.S.A.

Dear Bruce:

Subject: Non-Ceramic Insulators W.G.

Thank you for your letter of October 13, 1975 which enclosed the minutes of the two IEEE Working Groups on Non-Ceramic Insulators and Contamination.

Non-ceramic (polymer) outdoor insulators have long been the subject of top importance in our research and development programs. As you are well aware, the work covers a very wide range of study and requires patient tests and trials of many years. We have not yet reached any conclusive results on materials, designs or test methods to be applied to the polymer outdoor insulators.

I will try my best to outline for you our thinking and works presently underway on these insulators.

1. We think that the prospect of these insulators exists in two different areas of application. The one is the application where a very high mechanical strength is required, because of its easiness to attain such a strength with comparatively light weight. The other relates to a special structural application, taking an advantage of its easiness to design long structural members of small diameter, light weight and high strength.

2. The long term reliability, life and cost are the decisive factors in evaluating these insulators. At present, no one expects that these insulators has a perpetual life a life equivalent to that of existing ceramic insulators. Also, the environmental and application conditions are far more influential in the life of these

insulators than in the case of ceramic insulators, and, therefore, selection of material and economy of these insulators in comparison with ceramic insulators should be carefully weighed with regard for factors and conditions.

3. We are presently concentrating on one basic concept of design, that is, FRP core covered by polymer shed sleeve (or sheds) with metal fittings at both ends. At present, we are not considering the design of FRP core and porcelain sheds.

4. The major subject in our development work of these insulators are as follows;

   1) To obtain a reliable FRP core, particularly with very high strength.

   2) To find a reliable method of end fixing of metal fittings on FRP core.

   3) Selection of material for outer covering and matching between the core and covering materials.

   4) Life and reliability, tests and evaluation

      Electrical and physical: Surface and interface
      Mechanical : Core and end fixing

5. NGK has a technical and commercial licensing arrangement with REBOSIO INDUSTRIA ELETTROTECNICA of Italy, a licensor. This arrangement covers patent, knowhow, technical collaboration, marketing and other aspects on "Isoflon" which they have developed and have been commercially marketing and selling for some years in Europe. Accordingly, we are working intensively on "Isoflon". However, our work is not limited to "Isoflon" but covers other materials and designs too.

6. We have supplied a limited number of samples of these insulators to the domestic utilities and laboratories who have outdoor testing stands in order to observe their performance under voltage application under natural conditions and any change of surface or other portions. It is too premature to conclude any results, though we feel that these exposure tests have proved the vital improtance of the need of field trials in various locations in evaluating these insulators.

NGK INSULATORS, LTD.
MIZUHO, NAGOYA, JAPAN

Mr. B.E. Kingsbury

December 17, 1975

Bruce, frankly speaking I don't know at this stage what extent of disclosure of pertinent information to the WG on the subject is appropriate. At least, it would be fair to consider that such presentation of information to the WG should be made on an equal exchange basis, applicable to all participants. If the WG needs any details on specific matters, please let us know. Though Mr. Naito is one of the members of the WG, it is difficult for him to attend every meeting and, therefore, your advice on the subject and information on the progress of the WG would be very much appreciated.

Very truly yours,

I. Kimoto
Manager of Engineering Dept.
Insulator Group

P.S. Attached technical papers are summaries of our studies concerning polymer outdoor insulators.
Enclosed are copies of three Japanese papers and one English paper related to the subject matter. I am sorry that no English translations are available for the Japanese papers.
I hope that you will find the attached technical papers useful.

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DEC 23 1975

NEW ENGLAND RESEARCH APPLICATION CENTER
UNIVERSITY OF CONNECTICUT
STORRS, CONNECTICUT 06268

SDI/CA SEARCH
ENGINEERING INDEX FILE
ISSUE 12 1975

POLYMERIC INSULATORS

MR. R. WELLER
LOCKE INSULATORS
2525 INSULATOR DRIVE
BALTIMORE, MD 21230

COMPUTER RUN DATE 12/31/75 QUESTION NUMBER - 055093

EIX 75-12 00833

FLASHOVERS OF INSULATORS UNDER NATURAL POLLUTION AND HVDC.

HIRSCH, FRITZ RHEINBABEN, HUBERT V. SORMS, REINHOLD

IEEE TRANS POWER APPAR SYST V PAS-94 N 1 JAN-FEB 1975 P 45-50 , CODEN-IEPSA9, LOCATION OF WORK-FORSCHUNGSGEM FUER HOCHSPANNUNGS & HOCHSTROMTECH, MANNHEIM, GER, MONTHLY PUBLICATION NO.-080295, ITEM NUMBER-078354

IN THE DOSSENWALD TEST STATION, NEAR MANNHEIM, AN INSULATOR TESTFIELD FOR MORE THAN 30 TEST OBJECTS WAS CONSTRUCTED, FED BY A STIFF D. C. VOLTAGE SOURCE AND CONTROLLED BY AN AUTOMATIC TEST PROGRAM INSTALLATION. THE TESTED TYPES, 7 POST INSULATORS (PORCELAIN) AND 3 SUSPENSION INSULATORS (PORCELAIN, GLASS, SILICONE RUBBER), TWO SPECIMEN OF EACH TYPE IN PARALLEL, WERE CONTINUOUSLY UNDER 400 KV D. C. VOLTAGE, POSITIVE POLARITY, FOR MORE THAN 8000 H. FLASHOVERS DURING THAT TIME WERE ANALYZED. 16 REFS.

CONTAMINATION
ELECTRIC INSULATORS
FLASHOVER
HIRSCH, FRITZ
HVDC SYSTEMS
INSULATORS
POLLUTION
SORMS, REINHOLD
ELECTRIC ARCS
ELECTRIC POWER TRANSMISSION, D
FLASHOVERS
HVDC
IEPSA9
NATURAL
RHEINBABEN, HUBERT V.
UNDER

EIX 75-12 00835

GUIDE FOR APPLICATION OF INSULATORS TO WITHSTAND SWITCHING SURGES.

REP

IEEE TRANS POWER APPAR SYST V PAS-94 N 1 JAN-FEB 1975 P 58-67 , CODEN-IEPSA9, MONTHLY PUBLICATION NO.-080293, ITEM NUMBER-078356

THE SWITCHING SURGE STRENGTH OF TRANSMISSION LINE INSULATION IS DISCUSSED. A GUIDE TO EVALUATE THE IMPORTANCE OF DIFFERENT VARIABLES INFLUENCING INSULATION STRENGTH AND THEIR IMPACT ON LINE INSULATION DESIGN IS REVIEWED, AND CURVES SHOWING THE LINE FLASHOVER RATE FOR DIFFERENT INSULATION CHARACTERISTICS ARE PRESENTED. 47 REFS.

APPLICATION
ELECTRIC LINES
GUIDE
INSULATORS
SURGES
TESTING
ELECTRIC INSULATION
FLASHOVER
IEPSA9
REP
SWITCHING
WITHSTAND

EIX 75-12 01926

LIQUID RESIN MOLDING OF TRANSFORMERS AND BUSHINGS.

SHEERER, GEORGE D. BULANDA, S. E. BAUER, STEPHEN H.

SPE TECH CONF, 33RD ANNU, PROC, ATLANTA, GA, MAY 5-8 1975 P 230-232. PUBL BY SPE, GREENWICH, CONN, 1975 , LOCATION OF WORK-DEXTER CORP, OLEAN, NY, MONTHLY PUBLICATION NO.-083184, ITEM NUMBER-079447

THIS PAPER DESCRIBES AND EVALUATES THE LIQUID RESIN MOLDING (LRM) SYSTEM WITH EMPHASIS ON ITS APPLICATIONS IN THE MANUFACTURE OF ELECTRIC TRANSFORMERS AND BUSHINGS OF ELECTRIC INSULATORS. A BASIC LRM SYSTEM CONSISTS OF A CLAMPING DEVICE, MASTER CONTROL PANEL, PROPORTIONING EQUIPMENT AND MOLD, ALL JOINED IN A SINGLE PIECE OF EQUIPMENT. THE EQUIPMENT IS EASILY CONTROLLED FROM A MASTER PANEL, WITH FUNCTIONS OF INJECTION TIME, INJECTION HOLD, AND CLAMP CLOSE TIME CONTROLLED BY AUTOMATIC TIMERS. PROPER SETTINGS OF THE TIMERS DETERMINE THE EXACT AMOUNT OF MATERIAL DISPENSED AND INSURE EASY PART REMOVAL AT THE END OF THE GEL CYCLE. DETAILS OF THE PROCESS AND EQUIPMENT ARE GIVEN. 6 REFS.

BAUER, STEPHEN H.
BUSHINGS
ELECTRIC TRANSFORMERS
LIQUID RESIN MOLDING
MANUFACTURE
PLASTICS
SHEERER, GEORGE D.
BULANDA, S. E.
ELECTRIC INSULATORS
LIQUID
LIQUIDS
MOLDING
RESIN
TRANSFORMERS

EIX 75-12 02300

STRUCTURE AND ENERGY OF THE INTERFACE BETWEEN AN INSULATOR AND AN ELECTROLYTE.

WILLIAMS, RICHARD

RCA REV V 36 N 3 SEP 1975 P 542-550 , CODEN-RCARAG, LOCATION OF WORK-RCA LAB, PRINCETON, NJ, MONTHLY PUBLICATION NO.-080533, ITEM NUMBER-079821

THE SURFACE TENSION OF WATER IS INCREASED BY THE ADDITION OF A SOLUBLE IONIC SALT. IN THIS WORK IT IS SHOWN THAT THERE IS A SIMILAR INCREASE IN THE INTERFACIAL FREE ENERGY BETWEEN THE AQUEOUS SOLUTION AND A POLYMER. THE ORIGIN OF THESE EFFECTS CAN BE TRACED TO ELECTROSTATIC FORCES THAT DEPLETE THE IONS FROM A THIN LAYER OF WATER NEAR THE INTERFACE. IN AN IDEALIZED MODEL OF INTERFACE, IT IS REPRESENTED AS A THIN LAYER OF PURE WATER SANDWICHED BETWEEN THE BULK SOLUTION AND AN INSULATOR. GENERALLY SPEAKING, THE FREE ENERGY OF PURE WATER IS HIGHER THAN THAT OF WATER CONTAINING DISSOLVED IONS. BY ANALYZING THIS IDEA QUANTITATIVELY IT IS POSSIBLE TO CALCULATE THE ENERGY OF THE INTERFACE AS A FUNCTION OF THE CONCENTRATION OF DISSOLVED SALT. 14 REFS.

BETWEEN
ELECTROLYTE
INSULATOR
LIQUIDS
ELECTROCHEMISTRY
ENERGY
INTERFACE
RCARAG

BETWEEN
ELECTROLYTE
INSULATOR
LIQUIDS

INTERFACE
RCARAG

SURFACE TENSION

STRUCTURE
WILLIAMS, RICHARD

EIX 75-12 06870

LE CONTOURNEMENT DES ISOLATEURS HAUTE TENSION. APPROCHE A L'AIDE D'UN MODELE DE LABORATOIRE. (FLASHOVER OF HIGH VOLTAGE INSULATORS. APPROACH BY MEANS OF A LABORATORY MODEL) .

HURAUX, CLAUDE RAHAL, ABDELKADER MAHIEDDIN

REV GEN ELECTR V 84 N 6 JUN 1975 P 425-429 , CODEN-RGELAC, LOCATION OF WORK-UNIV PAUL SABATIER, TOULOUSE, FR, MONTHLY PUBLICATION NO.-080294, ITEM NUMBER-084391

THE PROPAGATION OF A DISCHARGE ON THE SURFACE OF A HIGH VOLTAGE INSULATOR IS SIMULATED IN A LABORATORY SYSTEM UNDER THE CONTROL OF SOME PARAMETERS: THE ELECTRICAL CHARACTERISTICS OF THE DISCHARGE CAN BE DEDUCED FROM THE EQUIVALENT CIRCUIT BUT ITS DYNAMIC BEHAVIOR CANNOT BE PREDICTED. TWO HYPOTHESIS ARE PROPOSED, CONCERNING THE MECHANISM WHICH CONTROLS THE PROPAGATION; THE TIME TO FLASHOVER CAN BE COMPUTED; THE RESULTS, MATCHED WITH THE EXPERIMENTS, SHOW THAT THIS APPROACH IS OF INTEREST; IT GIVES A NEW EMPHASIS TO THE PROBLEM OF THE DISAGREEMENT BETWEEN THE MEASURED FLASHOVER VOLTAGE AND THE VALUES FROM THE EQUIVALENT CIRCUIT. 11 REFS. IN FRENCH.

APPROACH
ELECTRIC INSULATORS
HIGH
INSULATORS
MEANS
RAHAL, ABDELKADER MAHIEDDIN
TESTING
ELECTRIC INSULATION
FLASHOVER
HURAUX, CLAUDE
LABORATORY
MODEL
RGELAC
VOLTAGE

NUMBER OF HITS WAS 5

QUES.	CD.	T	F	TERM	HIT	LIMIT	COPY
055093	1	98	1	PORCELAIN*		500	1C
055093	2	98	1	CERAMIC*			
055093	3	99	1	ELECTRIC INSULATOR*	X		
055093	4	99	98	INSULATOR*	X		

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MR. R. WELLER
LOCKE INSULATORS
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BALTIMORE, MD 21230

RESEARCH RETRIEVAL APPLICATION

NERAC

NEW ENGLAND RESEARCH APPLICATION CENTER
MANSFIELD PROFESSIONAL PARK
UNIVERSITY OF CONNECTICUT, STORRS, CONN.
(203) 486 - 4533 06268

NEW ENGLAND RESEARCH APPLICATION CENTER
UNIVERSITY OF CONNECTICUT
STORRS, CONNECTICUT 06268

SDI/CA SEARCH
ENGINEERING INDEX FILE
ISSUE 1 1976

POLYMERIC INSULATORS

MR. R. WELLER
LOCKE INSULATORS
2525 INSULATOR DRIVE
BALTIMORE, MD 21230

QUESTION NUMBER 055093 STRATEGY DATE IS 11/17/75 RUN DATE IS 01/28/76

EIX 76-01 01256

ZUR THEORIE DES UEBERSCHLAGS VON KAPPENISOLATOREN MIT UNTERSCHIEDLICHER VERSCHMUTZUNG DER SCHIRMOBER- UND -UNTERSEITE. (THEORY OF THE FLASHOVER OF CAP-TYPE INSULATORS WITH DIFFERENT CONTAMINATION OF THE LOWER AND UPPER SIDE OF THE SHIELD) .

SOLOMONIK, E. A. TICHODEJEW, N. N.

ELEKTRIE V 28 N 11 1974 P 585-587 , CODEN-EKTRAO, LOCATION OF WORK-FORSCHUNGSINST FUER GLEICHSTROM, LENINGRAD, USSR, MONTHLY PUBLICATION NO.-001887, ITEM NUMBER-001256

THE THEORY OF FLASHOVER OF CONTAMINATED CAP-AND-PIN TYPE INSULATORS IS EXTENDED TO THE FLASHOVER INSULATORS PRESENTING DIFFERENT CONDITIONS ON THE LOWER AND UPPER SIDE. EQUATIONS ARE ESTABLISHED FOR THE CREEPING FLASHOVER VOLTAGES. 10 REFS. IN GERMAN.

CAP-TYPE
CONTAMINATION
EKTRAO
FLASHOVER
LOWER
SIDE
THEORY
UPPER

CAP-TYPE INSULATORS
DIFFERENT
ELECTRIC INSULATORS
INSULATORS
SHIELD
SOLOMONIK, E. A.
TICHODEJEW, N. N.

EIX 76-01 01745

INFLUENCE OF THE WAVEFRONT OF IMPULSE VOLTAGES ON THE SPARKOVER OF ROD GAPS AND INSULATORS.

ALLIBONE, T. E. DRING, D.

PROC INST ELECTR ENG (LOND) V 122 N 2 FEB 1975 P 235-238 , CODEN-PIEEAH, LOCATION OF WORK-UNIV OF LEEDS, YORKSHIRE, ENGL, MONTHLY PUBLICATION NO.-001886, ITEM NUMBER-001745

THE INFLUENCE OF THE DURATION OF THE WAVEFRONT OF AN IMPULSE VOLTAGE ON THE SPARKOVER OF ROD GAPS, UP TO 80 CM, AND INSULATORS HAS BEEN DETERMINED FOR VOLTAGES OF BOTH POLARITIES UP TO 500 KV AND FOR TIMES TO CREST FROM 2 TO 140 MU SEC. THE PATTERN OF SPARKOVER AS THE WAVEFRONT (T//1) INCREASES IS A COMPLICATED ONE; FOR SMALL GAPS, THE POSITIVE-IMPULSE SPARKOVER FIRST RISES AND THEN FALLS AS THE WAVEFRONT INCREASES, THE REVERSE BEHAVIOR TO THAT OF LARGE GAPS. WITHSTAND VOLTAGES FOLLOW CURVES SIMILAR IN SHAPE TO THOSE OF THE CRITICAL-SPARKOVER-VOLTAGE CURVES AS T//1 VARIES, AND THE VALUE OF ROD GAPS FOR COORDINATION OF INSULATION TESTS IS QUESTIONED. THE EFFECTIVENESS OF A RADIATION SOURCE IN SPHERE-GAP VOLTAGE MEASUREMENT IS DEMONSTRATED AND ITS USE AGAIN RECOMMENDED. 16 REFS.

ALLIBONE, T. E.
ELECTRIC INSULATORS

DRING, D.
ELECTRIC SPARK GAPS

GAPS
INFLUENCE
PIEEAH
SPARKOVER
WAVEFRONT
IMPULSE
INSULATORS
ROD
VOLTAGES

EIX 76-01 01937

CONTACT ELECTRIFICATION BETWEEN INSULATORS: PHENOMENOLOGICAL ASPECTS

RUCKDESCHEL, F. R. HUNTER, L. P.

J APPL PHYS V 46 N 10 OCT 1975 P 4416-4430 , CODEN-JAPIAU, LOCATION OF WORK-UNIV OF ROCHESTER, NY, MONTHLY PUBLICATION NO.-002182, ITEM NUMBER-001937

A MODIFIED FORM OF PETERSON'S ROTATING FARADAY CAGE IS EMPLOYED TO STUDY THE DEPENDENCE OF ELECTRIFICATION ON THE RATE AT WHICH CONTACTING INSULATOR SURFACES ARE SEPARATED. IT IS DETERMINED THAT THE RELEVANT PARAMETERS ARE THE SURFACE-CHARGE DENSITIES AND THE PERPENDICULAR VELOCITY OF SEPARATION, INDEPENDENT OF THE SIZE OF BEAD USED. AIR-DISCHARGE AND FUNCTIONAL-HEATING EFFECTS WERE OBSERVED AND AVOIDED. DESORPTION EXPERIMENTS INDICATE THAT WATER PLAYS A ROLE IN THE ELECTRIFICATION PROCESS OF AL//2O//3 VS VARIOUS GLASSES. 30 REFS.

ASPECTS
CONTACT
ELECTROSTATICS
INSULATORS:
PHENOMENOLOGICAL
BETWEEN
ELECTRIFICATION
HUNTER, L. P.
JAPIAU
RUCKDESCHEL, F. R.

EIX 76-01 02236

MICROWAVE HALL MEASUREMENT TECHNIQUES ON LOW MOBILITY SEMICONDUCTORS AND INSULATORS $EM DASH$ 1. ANALYSIS.

SAYED, MOHAMED M. WESTGATE, CHARLES R.

REV SCI INSTRUM V 46 N 8 AUG 1975 P 1074-1079 , CODEN-RSINAK, LOCATION OF WORK-JOHNS HOPKINS UNIV, BALTIMORE, MD, MONTHLY PUBLICATION NO.-002845, ITEM NUMBER-002236

THE RELATIONSHIPS OF MICROWAVE HALL MOBILITIES AND MICROWAVE CONDUCTIVITIES IN A SEMICONDUCTOR, PLACED AT THE CENTER OF A DUAL MODE TE//1//1//1 CAVITY, ARE EXPRESSED IN TERMS OF THE LOADED AND UNLOADED VOLTAGE REFLECTION COEFFICIENTS, THE SAMPLE AND THE CAVITY DIMENSIONS, THE RATIO OF THE OUTPUT POWER TAO THE INPUT POWER OF THE CAVITY, AND THE MAGNETIC FIELD. SCATTERING MATRIX ANALYSIS AND PERTURBATION THEORY ARE USED. 27 REFS.

ANALYSIS
HALL
INSULATORS
MEASUREMENT
MICROWAVE HALL MOBILITY
RSINAK
ELECTRIC INSULATORS
HALL EFFECT
LOW
MICROWAVE
MOBILITY
SAYED, MOHAMED M.

SEMICONDUCTOR MATERIALS
TECHNIQUES

SEMICONDUCTORS
WESTGATE, CHARLES R.

EIX 76-01 02237

MICROWAVE HALL MEASUREMENT TECHNIQUES ON LOW MOBILITY SEMICONDUCTORS AND INSULATORS $EM DASH$ 2. EXPERIMENTAL PROCEDURES.

SAYED, MOHAMED M. WESTGATE, CHARLES R.

REV SCI INSTRUM V 46 N 8 AUG 1975 P 1080-1085 , CODEN-RSINAK, LOCATION OF WORK-JOHNS HOPKINS UNIV, BALTIMORE, MD, MONTHLY PUBLICATION NO.-002846, ITEM NUMBER-002237

AN EXPERIMENTAL TECHNIQUE FOR THE MEASUREMENT OF HALL MOBILITIES AT MICROWAVE FREQUENCIES IS DESCRIBED. THE DESIGN OF A DUAL MODEL TE//1///1///1 CAVITY IS DESCRIBED, AND A COMPARISON AMONG RECEIVERS FOR THE DETECTION SYSTEM IS GIVEN. A PROCEDURE FOR TUNING THE CAVITY FOR ORTHOGONALITY, DEGENERACY, AND EQUAL QUALITY FACTORS IS PRESENTED. WITH A SUPERHETERODYNE RECEIVER AND A WELL-DESIGNED GOLD-PLATED PROBE-COUPLED CAVITY, THE MINIMUM DETECTABLE MOBILITY IS 0. 07 CM**2/V $MULTIPLIED BY (TIMES)$ SEC FOR A HIGH CONDUCTIVITY SAMPLE. 13 REFS.

ELECTRIC INSULATORS
HALL
INSULATORS
MEASUREMENT
MICROWAVE HALL MOBILITY
PROCEDURES
SAYED, MOHAMED M.
SEMICONDUCTORS
WESTGATE, CHARLES R.
EXPERIMENTAL
HALL EFFECT
LOW
MICROWAVE
MOBILITY
RSINAK
SEMICONDUCTOR MATERIALS
TECHNIQUES

EIX 76-01 02737

ELECTRON EMISSION OF METALS INTO INSULATORS.

VODENICHAROV, C. M.

PHYS STATUS SOLIDI (A) APPL RES V 29 N 1 MAY 1975 P 223-230 , CODEN-PSSABA, LOCATION OF WORK-INST OF CHEM TECHNOL, SOFIA, BULG, MONTHLY PUBLICATION NO.-005622, ITEM NUMBER-002737

ON THE BASIS OF THE UNIFIED THEORY OF ELECTRON EMISSION OF METALS INTO INSULATORS BY CHRISTOV, THE FIELD AND TEMPERATURE DEPENDENCES OF THE CURRENT DENSITY IN THE ENTIRE REGION BETWEEN THE THERMIONIC AND THE FIELD EMISSION ARE PRESENTED GRAPHICALLY WHEREBY TYPICAL VALUES FOR THE METAL-INSULATOR WORK FUNCTION AND FOR THE DIELECTRIC CONSTANT OF THE INSULATOR HAVE BEEN EMPLOYED. THE THEORETICAL CURVES ARE PRESENTED IN DIMENSIONLESS COORDINATES USING THE CHARACTERISTIC TEMPERATURES INTRODUCED BY CHRISTOV, WHICH ARE TABULATED. TABLES ARE PRESENTED FOR THE VALUES OF THE CORRECTION FACTORS TO THE EQUATIONS OF RICHARDSON-SCHOTTKY AND FOWLER-NORDHEIM IN THE EXTENDED REGIONS OF THE THERMIONIC AND FIELD EMISSION, RESPECTIVELY, AS WELL AS FOR THE CORRESPONDING FACTORS IN THE GENERAL EQUATION FOR THE

CURRENT DENSITY. 18 REFS.

ELECTRON
EMISSION
INTO
PSSABA
VODENICHAROV, C. M.
ELECTRONIC PROPERTIES
INSULATORS
METALS
SEMICONDUCTOR MATERIALS

EIX 76-01 05057

THEORETICAL TRANSDUCER PROPERTIES OF PIEZOELECTRIC INSULATOR FET TRANSDUCERS.

GREENEICH, E. W. MULLER, R. S.

J APPL PHYS V 46 N 11 NOV 1975 P 4631-4640 , CODEN-JAPIAU, LOCATION OF WORK-UNIV OF CALIF, BERKELEY, MONTHLY PUBLICATION NO.-004623, ITEM NUMBER-005057

AN ORIENTED PIEZOELECTRIC FILM INCORPORATED IN THE INSULATOR REGION OF A SILICON INSULATED-GATED FIELD-EFFECT TRANSISTOR (FET) RESULTS IN A SENSITIVE HIGH-FREQUENCY STRAIN TRANSDUCER. THEORY GOVERNING THE TRANSDUCER PROPERTIES OF THE PIEZOELECTRIC INSULATOR FET TRANSDUCER IS PRESENTED. EQUATIONS ARE DEVELOPED WHICH RELATE THE DRAIN CURRENT OF THE DEVICE TO INDUCED POLARIZATIONS OF THE PIEZOELECTRIC LAYER. THE HIGHEST FREQUENCY OF SURFACE STRAINS TO WHICH THE FET TRANSDUCER CAN RESPOND IS DETERMINED BY THE FET FREQUENCY RESPONSE. THIS FREQUENCY CAN EXTEND TO THE GHZ RANGE. 15 REFS.

FET
INSULATOR
MULLER, R. S.
PIEZOELECTRIC TRANSDUCERS
THEORETICAL
TRANSDUCERS
GREENEICH, E. W.
JAPIAU
PIEZOELECTRIC
PROPERTIES
TRANSDUCER

EIX 76-01 05616

HIGH TEMPERATURE CRYSTAL CHEMISTRY OF V//2O//3 THROUGH THE METAL-INSULATOR TRANSITION AND OF (CR//O//. //O//1V//O//. //9//9)//2O//3, AN INSULATOR.

ROBINSON, WILLIAM R.

EXTENDED INTERACT BETWEEN MET IONS IN TRANSITION MET COMPLEXES, SYMP, PROC, AM CHEM SOC, 167TH MEET, LOS ANGELES, CALIF, APR 3-5 1974 P 16-22. PUBL BY AM CHEM SOC (ACS SYMP SER 5), WASHINGTON, DC, 1974 , LOCATION OF WORK-PURDUE UNIV, WEST LAFAYETTE, INDIANA, MONTHLY PUBLICATION NO.-006779, ITEM NUMBER-005616

THEORETICAL CONSIDERATION OF STRUCTURAL AND ELECTRICAL PHENOMENA WHICH ARE OBSERVED UPON HEATING THE CHROMIUM DOPED V//2O//3 SYSTEM, (CR//XV//1// $MINUS$ //X)//2O//3 COMPLEX COMPOUND, ARE FOLLOWED BY A DESCRIPTION OF AN EXPERIMENTAL INVESTIGATION IN WHICH CRYSTALLOGRAPHIC DATA WERE OBTAINED WITH MEASUREMENT OF METAL-TO-METAL DISTANCE AS A FUNCTION OF TEMPERATURE. IT IS DEMONSTRATED THAT THE STRUCTURAL CHANGES IN V//2O//3 UPON

HEATING INVOLVE A SLIGHT REDUCTION OF THE SPACING BETWEEN THE APPROXIMATELY HEXAGONALLY CLOSEST PACKED PLANES OF OXYGEN ATOMS WITH A CONCOMMITANT INCREASE IN THE AVERAGE OXYGEN-OXYGEN SEPARATION IN THE PLANES. ONE CAN DISTINGUISH TWO TYPES OF OXYGEN-OXYGEN DISTANCES WITHIN A GIVEN PLANE; DISTANCES OF THE TYPE O//1-O//2 ALONG THE EDGE OF A SHARED OCTAHEDRAL FACE AND DISTANCES OF THE TYPE O//1-O//3 OR O//4-O//5 ALONG THE EDGES OF AN UNSHARED FACE. IT IS EXPANSION OF THE OXYGEN-OXYGEN DISTANCES ALONG THE EDGES OF THE UNSHARED FACE WHICH IS REFLECTED IN THE INCREASE IN THE A AXIS. PARALLELING THE INCREASE IN THE A AXIS IS THE M//1-M//3 SEPARATION. THE M//1-M//2 DISTANCE INCREASES AT THE SAME RATE AS THE M//1-M//3 DISTANCE. THE NET RESULT OF THESE CHANGES IS THAT AT HIGH TEMPERATURES V//2O//3, WHICH IS ISOSTRUCTURAL WITH $ALPHA$ -(CR//O//. //O//1V//O//. //9//9)//2O//3 AT ROOM TEMPERATURE, BECOMES ISOSTRUCTURAL WITH $BETA$ -(CR//O//. //O//1V//O//. //9//9)//2O//3 AND (CR//O//. //O//4V//O//. //9//6)//2O//3. 13 REFS.

(CR//O//
//9//9)//2O//3
CHROMIUM COMPOUNDS
CRYSTALS
HIGH
INSULATOR TO METAL TRANSITION
METALLIC COMPOUNDS
ROBINSON, WILLIAM R.
TEMPERATURE
TRANSITION METAL COMPLEXES
VANADIUM COMPOUNDS
//O//1V//O//
CHEMISTRY
CRYSTAL
HEAT TREATMENT
INSULATOR
METAL-INSULATOR
PHYSICAL CHEMISTRY
STRUCTURE
TRANSITION
V//2O//3
VANADIUM OXIDE

EIX 76-01 06701

EINFACHE BESTIMMUNG DER SCHICHTLEITFAEHIGKEIT AUF ISOLATOREN IN DER PRAXIS. (SIMPLE DETERMINATION OF THE SHEATH CONDUCTIVITY ON INSULATORS IN PRACTICE) .

SCHWAB, F.

BULL ASSOC SUISSE ELECTR V 66 N 14 JUL 19 1975 P 757-759 , CODEN-BUSEAH, LOCATION OF WORK-AARE-TESSIN, OLTEN, SWITZ, MONTHLY PUBLICATION NO.-001888, ITEM NUMBER-006701

BY MEANS OF AN EASILY AFFECTED FUMIGATION IT IS POSSIBLE TO DIFFERENTIATE BETWEEN ACUTE AND CHRONIC DECREASE OF INSULATION CAPACITY IN INSULATORS. THE DETERMINATION OF THE SPECIFIC SURFACE CONDUCTIVITY USING THE FORM FACTOR, ITS MEASUREMENT AND INTERPRETATION ARE DESCRIBED. 2 REFS. IN GERMAN.

BUSEAH
DETERMINATION
ELECTRIC INSULATORS
PRACTICE
SHEATH
CONDUCTIVITY
ELECTRIC CONDUCTIVITY
INSULATORS
SCHWAB, F.
SIMPLE

NUMBER OF HITS WAS 9

QUES.	CD.	T	F	TERM	HIT	LIMIT	COPY
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055093	2	98	1	CERAMIC*			
055093	3	99	1	ELECTRIC INSULATOR*	X		
055093	4	99	98	INSULATOR*	X		

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White Rubber Co., The, Ravenna, OH

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J.F. Enterprises, Truth or Consequences, NM
Keystone Helicopter Corp., West Chester, PA
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Commonwealth Associates Inc., Jackson, MI
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Ferguson, Brosz & Associates Limited, Scarborough, Ontario, Canada
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Henkels & McCoy, Inc., Blue Bell, PA
Miner and Miner, Consulting Engineers, Inc., Greeley, CO
Pole Control, Inc., Spring Park, MN
Stanley Consultants, Inc., Muscatine, IA
Telcom Engineering Inc., St. Louis Air Park, MO
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Heath International, Inc., Richmond, MI
Henkels & McCoy, Inc., Blue Bell, PA
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Pole Sprayers, Inc., Buffalo, NY
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Formed Plastics, Inc., Carle Place, L.I., NY
G E T Plastics, Inc., St. Louis, MO
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General Electric Co., Silicone Products Dept., Waterford, NY
General Gasket Corp., St. Louis, MO
Hardman Incorporated, Belleville, NJ
Johns-Manville Corp., Denver, CO
Keene Corporation Chase-Foster Division, East Providence, RI
Masonite Corporation, Chicago, IL
Owens Corning Fiberglas Corp., Toledo, OH
Reichhold Chemicals, Inc., White Plains, NY
Royal Industries, Tetrafluor Division, El Segundo, CA
Schlatter, H.A., Inc., Rockford, IL
Tapecoat Co., Inc., The, Evanston, IL
Zippertubing Co., The, Los Angeles, CA

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Graybar Electric Co., Inc., New York, NY
Hendrix Wire & Cable Corp., Milford, NH
Hubbard and Company, Emeryville, CA
I-T-E Imperial Corporation, Spring House, PA
Joslyn Mfg. & Supply Co., Chicago, IL
Joslyn Mfg. and Supply Co. - Pinco Div., Lima, NY
Knox Porcelain Corporation, Knoxville, TN
McGraw-Edison Power Systems Division, Canonsburg, PA
Moritani America, Inc., Chicago, IL
Ohio Brass Company, The, Mansfield, OH
Patterson Electric Co., Inc., Loughlintown, PA
Porcelain Products Company, Carey, OH
Porter, H. K., Company, Inc., Electrical Division, Pittsburgh, PA
Synthetic Products Mfg. Corp., Sub. Reliable Electric Co., Leominster, MA

INSULATORS—POLYMER

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G E T Plastics, Inc., St. Louis, MO
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Haveg Industries, Inc. - Industrial & Aerospace Div. - Sub. of Hercules, Inc., Taunton, MA
Ohio Brass Company, The, Mansfield, OH
Osborne Electric Co. Ltd., Toronto, Ontario M8Z 5M4, Canada
Permali, Inc., Mount Pleasant, PA
Permali, Inc. - Transmission Developments Div., Mt. Pleasant, PA
Rebosio, R.I.E. - Milano (Italy), New York, NY
Rosenthal Technik Werkqruppe I, West Germany
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INSULATORS—RUBBER

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Ohio Brass Company, The, Mansfield, OH
Oliver Division of Sangamo Electric Company, Vicksburg, MS
Patterson Electric Co., Inc., Loughlintown, PA
Porcelain Products Company, Carey, OH
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INSULATORS—STRAIN

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Knox Porcelain Corporation, Knoxville, TN
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Oliver Division of Sangamo Electric Company, Vicksburg, MS
Permali, Inc. - Transmission Developments Div., Mt. Pleasant, PA
Porcelain Products Company, Carey, OH
Porter, H. K., Company, Inc., Electrical Division, Pittsburgh, PA
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Shakespeare Industrial Products Division, Columbia, SC
Southern Porcelain, Inc., Marietta, GA
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Weaver, J. A., Co., St. Louis, MO

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Chance, A. B., Co., Utility Systems Div., Subs. of Emerson Electric Co., Centralia, MO
Cogenel, Inc., New York, NY
Graybar Electric Co., Inc., New York, NY
I-T-E Imperial Corporation, Spring House, PA
Joslyn Mfg. & Supply Co., Chicago, IL
Joslyn Mfg. and Supply Co. - Pinco Div., Lima, NY
Knox Porcelain Corporation, Knoxville, TN
Lapp Insulator Division, Interpace Corp., Le Roy, NY
Locke Insultors, Inc., Baltimore, MD
Moritani America, Inc., Chicago, IL
Ohio Brass Company, The, Mansfield, OH
Patterson Electric Co., Inc., Loughlintown, PA
Permali, Inc., Mount Pleasant, PA
Permali, Inc. - Transmission Developments Div., Mt. Pleasant, PA
Porcelain Products Company, Carey, OH
Porter, H. K., Company, Inc., Electrical Division, Pittsburgh, PA
Rosenthal Technik Werkqruppe I, West Germany
Sediver, Inc., Carlstadt, NJ
Southern Porcelain, Inc., Marietta, GA

INSULATORS—SWITCH AND BUS

Anixter-Pruzan, Inc., Seattle, WA
Chance, A. B., Co., Utility Systems Div., Subs. of Emerson Electric Co., Centralia, MO
Cogenel, Inc., New York, NY
Electrical Manufacturing Co. Ltd., Montmagny, Quebec, Canada
Glastic Corp., Cleveland, OH
Graybar Electric Co., Inc., New York, NY
I-T-E Imperial Corporation, Spring House, PA
Joslyn Mfg. & Supply Co., Chicago, IL
Joslyn Mfg. and Supply Co. - Pinco Div., Lima, NY
Lapp Insulator Division, Interpace Corp., Le Roy, NY
Locke Insultors, Inc., Baltimore, MD
Montel Inc., Montmagny, Quebec, Canada
Moritani America, Inc., Chicago, IL
Ohio Brass Company, The, Mansfield, OH
Permali, Inc. - Transmission Developments Div., Mt. Pleasant, PA
Porcelain Products Company, Carey, OH
Porter, H. K., Company, Inc., Electrical Division, Pittsburgh, PA
Rosenthal Technik Werkqruppe I, West Germany
Southern Porcelain, Inc., Marietta, GA
Southern States Inc. (Subsidiary of Gulton Industries Inc.), Hampton, GA
Structural Substations Inc., Gresham, OR
Westinghouse Electric Corporation, Pittsburgh, PA

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INSULATORS, GUY STRAIN—FIBER GLASS REINFORCED

Anderson Electrical Connectors, Square D Co., Leeds, AL
Anixter-Pruzan, Inc., Seattle, WA
Barron Bethea Company, Inc., Birmingham, AL
Cogenel, Inc., New York, NY
Continental Electric Co., Birmingham, AL
Dixie Electrical Mfg. Company, Birmingham, AL
Graybar Electric Co., Inc., New York, NY
Joslyn Mfg. & Supply Co., Chicago, IL
Kearney, Atlanta, GA
Permali, Inc. - Transmission Developments Div., Mt. Pleasant, PA
Plastigage Corporation, Jackson, MI
Rebosio, R.I.E. - Milano (Italy), New York, NY
Rosenthal Technik Werkqruppe I, West Germany
Schlatter, H.A., Inc., Rockford, IL
Shakespeare Industrial Products Division, Columbia, SC
Square D Company, Park Ridge, IL
Zippertubing Co., The, Los Angeles, CA

INSULATORS, GUY STRAIN—PORCELAIN

Anixter-Pruzan, Inc., Seattle, WA
Chance, A. B., Co., Utility Systems Div., Subs. of Emerson Electric Co., Centrailia, MO
Cogenel, Inc., New York, NY
Graybar Electric Co., Inc., New York, NY
Gulton Industries, Inc., Metuchen, NJ
I-T-E Imperial Corporation, Spring House, PA
Joslyn Mfg. & Supply Co., Chicago, IL
Joslyn Mfg. and Supply Co. - Pinco Div., Lima, NY
Knox Porcelain Corporation, Knoxville, TN
Lapp Insulator Division, Interpace Corp., Le Roy, NY
Moritani America, Inc., Chicago, IL
Ohio Brass Company, The, Mansfield, OH
Oliver Division of Sangamo Electric Company, Vicksburg, MS
Porcelain Products Company, Carey, OH
Rosenthal Technik Werkqruppe I, West Germany
Southern Porcelain, Inc., Marietta, GA

INSULATORS, POST—HORIZONTAL

Anixter-Pruzan, Inc., Seattle, WA
Chance, A. B., Co., Utility Systems Div., Subs. of Emerson Electric Co., Centrailia, MO
Cogenel, Inc., New York, NY
Glastic Corp., Cleveland, OH
Graybar Electric Co., Inc., New York, NY
I-T-E Imperial Corporation, Spring House, PA
Lapp Insulator Division, Interpace Corp., Le Roy, NY
Ohio Brass Company, The, Mansfield, OH
Patterson Electric Co., Inc., Loughlintown, PA
Permali, Inc. - Transmission Developments Div., Mt. Pleasant, PA

INSULATORS, POST—STATION

Anixter-Pruzan, Inc., Seattle, WA
Chance, A. B., Co., Utility Systems Div., Subs. of Emerson Electric Co., Centrailia, MO
Cogenel, Inc., New York, NY
Glastic Corp., Cleveland, OH
Graybar Electric Co., Inc., New York, NY
I-T-E Imperial Corporation, Spring House, PA
Lapp Insulator Division, Interpace Corp., Le Roy, NY
Locke Insultors, Inc., Baltimore, MD
Moritani America, Inc., Chicago, IL
Ohio Brass Company, The, Mansfield, OH
Patterson Electric Co., Inc., Loughlintown, PA
Permali, Inc., Mount Pleasant, PA
Permali, Inc. - Transmission Developments Div., Mt. Pleasant, PA
Porter, H. K., Company, Inc., Electrical Division, Pittsburgh, PA
Rosenthal Technik Werkqruppe I, West Germany
Southern Porcelain, Inc., Marietta, GA
Southern States Inc. (Subsidiary of Gulton Industries Inc.), Hampton, GA
Structural Substations Inc., Gresham, OR

INTERCOMS

AAVcom Inc., Phoenix, AZ
ADC Telecommunications, Minneapolis, MN
Dictograph Products, Inc., Meriden, CT
Dukane Corporation, St. Charles, IL
Fanon/Courier Corporation - Courier Products, Pasadena, CA
Graybar Electric Co., Inc., New York, NY
Lear Siegler, Inc., Santa Monica, CA
Q E I Inc., Springfield, NJ
RCA Service Co., Camden, NJ
Setcom Corporation, Mountain View, CA

INTERCOMS—TRUCK MOUNTED

Fanon/Courier Corporation - Courier Products, Pasadena, CA
Graybar Electric Co., Inc., New York, NY
P & R Industries, Portland, OR
Ratelco, Inc., Seattle, WA
Setcom Corporation, Mountain View, CA

INTERIORS—SERVICE TRUCKS

Morysville Body Works, Inc., Boyertown, PA
Nevlen Co., Inc., Wakefield, MA
Ohio Brass Company - Holan Division, Elyria, OH
Ohio Brass Company, The, Mansfield, OH
Tel-E-Lect, Inc., Minneapolis, MN

INTERRUPTERS—FAULT

Chance, A. B., Co., Utility Systems Div., Subs. of Emerson Electric Co., Centrailia, MO
Datametrics, a Sub. of I-T-E Imperial Corp., Wilmington, MA
Electrical Manufacturing Co. Ltd., Montmagny, Quebec, Canada
Esco Manufacturing Company, Greenville, TX
Federal Pacific Electric Company, Newark, NJ
General Cable Apparatus Division, Westminster, CO
General Electric Company, Schenectady, NY
Graybar Electric Co., Inc., New York, NY
Hi-Voltage Equipment Div., Joslyn Mfg. & Supply Co., Cleveland, OH
Hipotronics, Inc., Brewster, NY
I-T-E Imperial Corporation, Spring House, PA
Joslyn Mfg. & Supply Co., Chicago, IL
Kearney, Atlanta, GA
Majol Portable Power Systems, Nanuet, NY
McGraw-Edison Power Systems Division, Canonsburg, PA
Montel Inc., Montmagny, Quebec, Canada
Ross Engineering Corp., Campbell, CA
S&C Electric Company, Chicago, IL
Westinghouse Electric Corporation, Pittsburgh, PA

INTERRUPTERS—VACUUM

Chance, A. B., Co., Utility Systems Div., Subs. of Emerson Electric Co., Centrailia, MO
English Electric Corporation, The, Elmsford, NY
Esco Manufacturing Company, Greenville, TX
General Electric Company, Schenectady, NY
Hi-Voltage Equipment Div., Joslyn Mfg. & Supply Co., Cleveland, OH
I-T-E Imperial Corporation, Spring House, PA
ITT Jennings, San Jose, CA
Joslyn Mfg. & Supply Co., Chicago, IL
Kearney, Atlanta, GA
McGraw-Edison Power Systems Division, Canonsburg, PA
Power Switching Equipment, Inc., Mesquite, TX
Ross Engineering Corp., Campbell, CA
Southern States Inc. (Subsidiary of Gulton Industries Inc.), Hampton, GA
Turner Electric Corp., East St. Louis, IL
Westinghouse Electric Corporation, Pittsburgh, PA

INVERTERS

Brown Boveri Corporation, North Brunswick, NJ
Del Electronics Corp., Mt. Vernon, NY
Dual-Lite Co., Div. of The SoundScriber Corp., Newtown, CT
Elgar Corporation, San Diego, CA
English Electric Corporation, The, Elmsford, NY
Exide Power Systems Division, ESB Incorporated, Philadelphia, PA
General Electric Company, Schenectady, NY
Gould Inc., Industrial Battery Division, Trenton, NJ
Graybar Electric Co., Inc., New York, NY
Gulton Industries, Inc., Metuchen, NJ
Industrial Test Equipment Co., Port Washington, NY
Integrated Systems, Inc., Norcross, GA
Mag-Con Inc., St. Paul, MN
Microtran Company, Inc., Valley Stream, NY
Nife Incorporated, Copiague, NY
P & R Industries, Portland, OR
Peschel Instruments, Inc., Cape Coral, FL
Programmed Power, Inc., Sub. of Franklin Electric, Menlo Park, CA
Ratelco, Inc., Seattle, WA
Rochester Instrument Systems, Inc., Rochester, NY
Siemens Corp., Iselin, NJ
Solidstate Controls, Inc., Columbus, OH
Topaz Electronics, Inc., San Diego, CA
Westinghouse Electric Corporation, Pittsburgh, PA

JACKS—REEL

Anixter-Pruzan, Inc., Seattle, WA
Columbia Products Inc., Reel-O-Matic Div., Wrightsville, PA
Cope Cable Installation Equipment, Cyprus Cable Support Systems Co., Collegeville, PA
D & W Reel Lift Co., Middleton, WI
Duff-Norton Co., Charlotte, NC
General Machine Products Co., Inc., Trevose, PA
Graybar Electric Co., Inc., New York, NY
Greenlee Tool Co., Rockford, IL
Hycaloader Co., Inc., The, Lake Providence, LA
Hykon Mfg. Co., Alliance, OH
Riley Enterprises, Adrian, MI
Utility Tool & Body Co., Inc., Clintonville, WI
Weber Electric Mfg. Co., St. Clair Shores, MI

JACKS—VEHICLE STABILIZING

Duff-Norton Co., Charlotte, NC
Graybar Electric Co., Inc., New York, NY
Magline Inc., Pinconning, MI
Mobile Component & Vehicle Products, Inc., Harleysville, PA
Ohio Brass Company - Holan Division, Elyria, OH
Ohio Brass Company, The, Mansfield, OH
Tel-E-Lect, Inc., Minneapolis, MN

JUMPERS—METER SOCKET

Duncan Electric Company, Inc., Lafayette, IN
Eastern Specialty Co., The, Philadelphia, PA
Ekstrom Industries, Inc., c/o John C. Bell Associates, Livonia, MI
General Electric Company, Schenectady, NY
Graybar Electric Co., Inc., New York, NY
Pipetron Div. Western Technical Products, N. Hollywood, CA
Warshaw Electric Co., Inc., Jamaica, NY

KEYS—POLE

American Crossarm & Conduit Co., Chehalis, WA
Anixter-Pruzan, Inc., Seattle, WA
Chance, A. B., Co., Utility Systems Div., Subs. of Emerson Electric Co., Centrailia, MO
Joslyn Mfg. & Supply Co., Chicago, IL

KITS—CABLE SPLICING

Anixter-Pruzan, Inc., Seattle, WA
Automation Products Company, Austin, TX
Bishop Electric Division, Cedar Grove, NJ
Bowthorpe-Hellermann Ltd, England
CAM-LOK Division, Empire Products, Inc., Cincinnati, OH
Chance, A. B., Co., Utility Systems Div., Subs of Emerson Electric Co., Centralia, MO
Communications Technology Corp., Los Angeles, CA
Devcon Corporation, Danvers, MA
Dow Corning Corporation, Midland, MI
Elastimold Division Amerace Corp., Hackettstown, NJ
Epoxylite Corporation, The, Anaheim, CA
General Electric Co., Insulating Materials Dept., Schenectady, NY
Graybar Electric Co., Inc., New York, NY
Hexcel Corporation, Rezolin Div., Chatsworth, CA
Hysol Division-The Dexter Corporation, Olean, NY
Jerome Underground Transmission Equipment, Inc., Commack, L.I., NY
Joslyn Mfg. & Supply Co., Chicago, IL
Kearney, Atlanta, GA
Kerite Company, The, New York, NY
Mac Products Inc., Kearny, NJ
Mark Equipment Co., St. Louis, MO
O. Z. Electrical Mfg. Co. Inc., Brooklyn, NY
Okonite Company, The, Ramsey, NJ
Pikwhit Industries Inc., Glen Cove, NY
PLM Products, Cleveland, OH
Plymouth Rubber CO. Inc., Canton, MA
RTE Corporation, Waukesha, WI
Three 3M Company, Electro-Products Div., St. Paul, MN
Zippertubing Co., The, Los Angeles, CA

KITS—FIRST AID

Anixter-Pruzan, Inc., Seattle, WA
AO Safety Products, Div. of American Optical Corp., Southbridge, MA
Bullard, E. D. Company, Sausalito, CA
Graybar Electric Co., Inc., New York, NY
Kole Enterprises, Miami, FL
Mine Safety Appliances Company, Pittsburgh, PA
Signal-Stat Corp., Union, NJ
TSI Company, Flanders, NJ

KITS—STRESS CONE

Anixter-Pruzan, Inc., Seattle, WA
Burndy Corp., Norwalk, CT
Chance, A. B., Co., Utility Systems Div., Subs. of Emerson Electric Co., Centrailia, MO
Elastimold Division Amerace Corp., Hackettstown, NJ
G & W Electric Specialty Co., Blue Island, IL
General Electric Co., Insulating Materials Dept., Schenectady, NY
Hexcel Corporation, Rezolin Div., Chatsworth, CA
ITT Blackburn Company, St. Louis, MO
Jerome Underground Transmission Equipment, Inc., Commack, L.I., NY
Joslyn Mfg. & Supply Co., Chicago, IL
Joy Manufacturing Company, New Philadelphia, OH
Kearney, Atlanta, GA
Mac Products Inc., Kearny, NJ
Pikwhit Industries Inc., Glen Cove, NY
PLM Products, Cleveland, OH
Plymouth Rubber CO. Inc., Canton, MA
Three 3M Company, Electro-Products Div., St. Paul, MN

KITS—TERMINATING

Alcon, Inc., Loveland, OH
Anixter-Pruzan, Inc., Seattle, WA
Bishop Electric Division, Cedar Grove, NJ
Chance, A. B., Co., Utility Systems Div., Subs. of Emerson Electric Co., Centrailia, MO
Communications Technology Corp., Los Angeles, CA
Elastimold Division Amerace Corp., Hackettstown, NJ
Epoxylite Corporation, The, Anaheim, CA
General Electric Co., Insulating Materials Dept., Schenectady, NY
Graybar Electric Co., Inc., New York, NY
Hexcel Corporation, Rezolin Div., Chatsworth, CA
ITT Blackburn Company, St. Louis, MO
Joslyn Mfg. & Supply Co., Chicago, IL
Kearney, Atlanta, GA
Kerite Company, The, New York, NY
Mac Products Inc., Kearny, NJ
O. Z. Electrical Mfg. Co. Inc., Brooklyn, NY
Okonite Company, The, Ramsey, NJ
Pikwhit Industries Inc., Glen Cove, NY
PLM Products, Cleveland, OH
Plymouth Rubber CO. Inc., Canton, MA
RTE Corporation, Waukesha, WI
Teledyne Penn-Union Electric, Edinboro, PA
Three 3M Company, Electro-Products Div., St. Paul, MN

KNIVES—CABLE SHEATH SPLITTING

Anixter-Pruzan, Inc., Seattle, WA
Graybar Electric Co., Inc., New York, NY
Ideal Industries, Inc., Sycamore, IL
Klein, Mathias & Sons, Inc., Chicago, IL
Mann, Henry Inc., Huntingdon Valley, PA
Neuses, P. K., Inc., Rolling Meadows, IL

KNIVES—LINEMEN'S

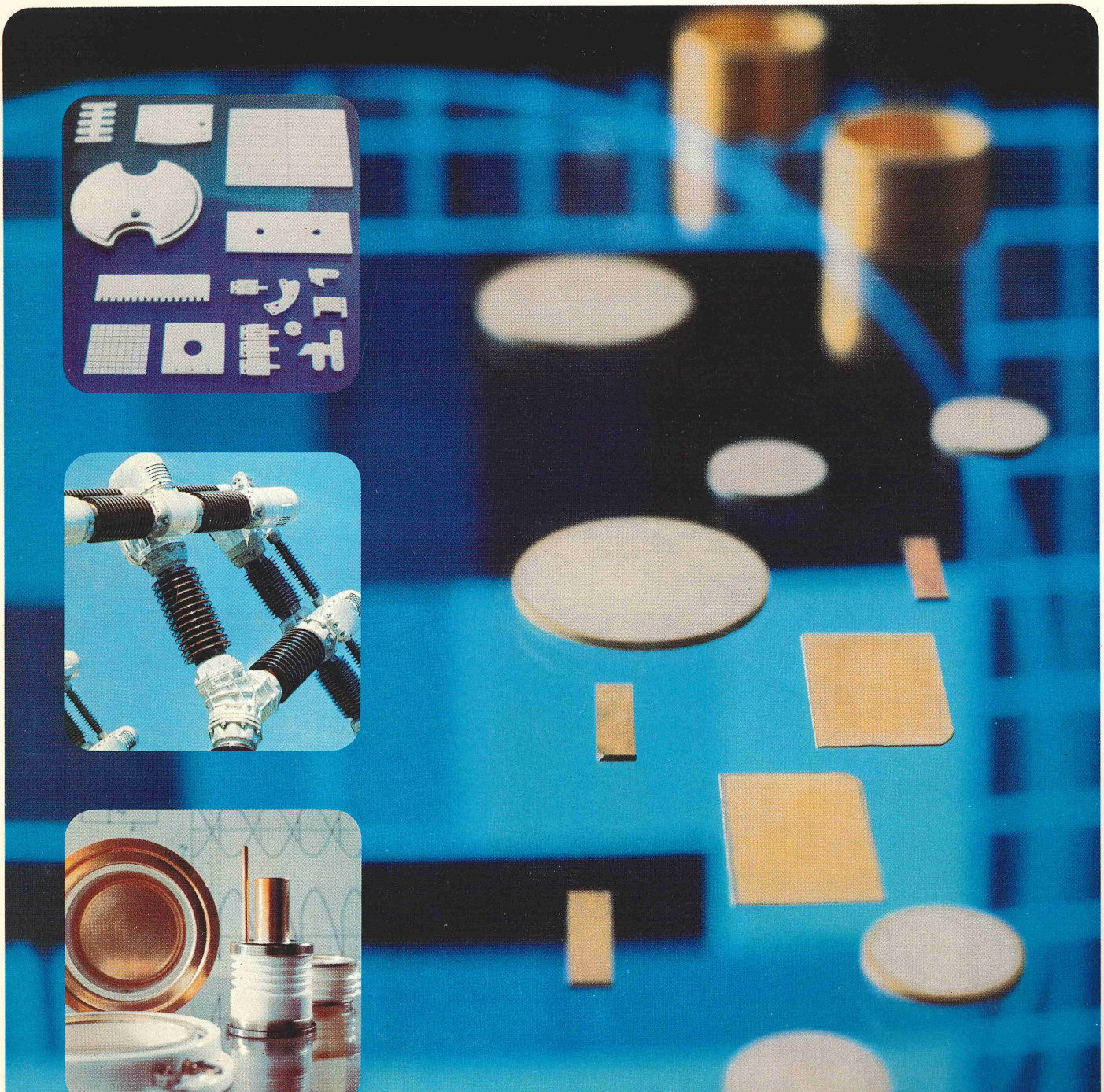
Anixter-Pruzan, Inc., Seattle, WA
Bartlett Manufacturing Co., Detroit, MI
Bashlin, W. M. Company, Grove City, PA
Graybar Electric Co., Inc., New York, NY
I-T-E Electrical Components Group, East Farmingdale, NY
ITT Holub Industries, Sycamore, IL
Klein, Mathias & Sons, Inc., Chicago, IL
Mann, Henry Inc., Huntingdon Valley, PA
Miller Equipment Division, ESB Incorporated, Franklin, PA
Safety Live Line Tool Co., Oakland, CA

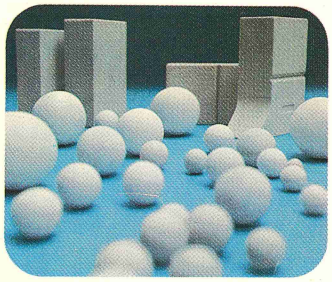
LABELS (SEE ALSO MARKERS)

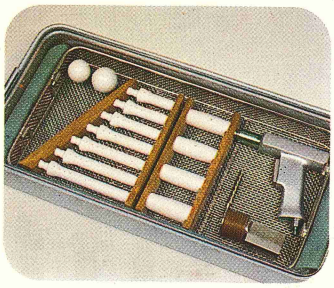
Anixter-Pruzan, Inc., Seattle, WA
Brady W. H. Co., Milwaukee, WI
Emblem Tape & Label Co., Denver, CO
Graybar Electric Co., Inc., New York, NY
Kraftbilt Products, Tulsa, OK
Neeco Industries Ltd., Burlington, Ontario
Primark Products Co., Santa Ana, CA

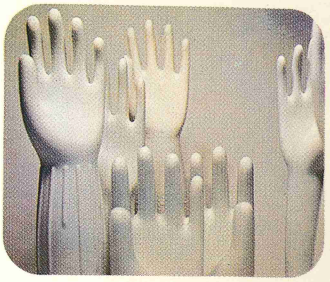
Rosenthal technik

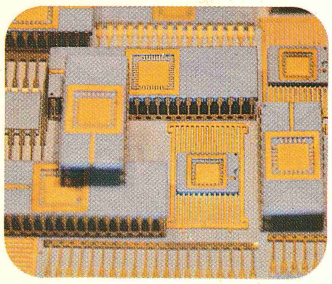
Rosenthal Technik AG
Werksgruppe I





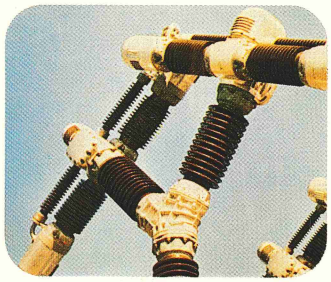


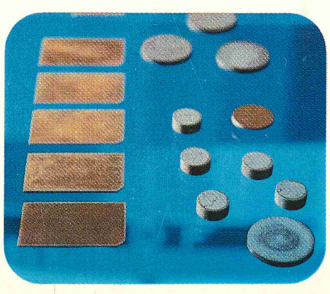


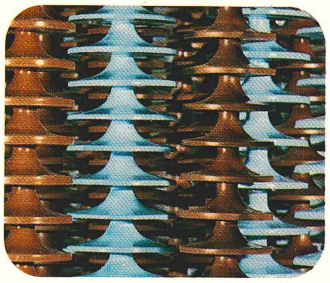


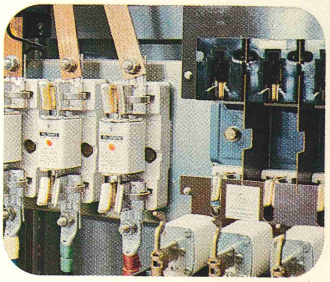
Die Rosenthal Technik AG, eines der größten Unternehmen der technischen Keramik auf dem Weltmarkt, entstand 1971 aus den Fertigungsstätten der technischen Keramik der früheren Rosenthal-Isolatoren GmbH (RIG) Selb, der Rosenthal Technischen Werke (RTW) Marktredwitz und der Steatit-Magnesia AG (STEMAG) Lauf. Organisatorisch gehört die Rosenthal Technik AG zur Rosenthal-Gruppe. Sie ist in drei selbständige Werksgruppen gegliedert. Jede Werksgruppe umfaßt Produktion, Produktentwicklung und Vertrieb bestimmter Erzeugnisse aus dem gesamten Lieferprogramm.

Das Fertigungsprogramm der Rosenthal Technik AG umfaßt die volle Breite von Produkten der technischen Keramik aus nahezu allen derzeit in der modernen Industrie benötigten Werkstoffen. Modernste Fertigungsverfahren, verbunden mit dem Erfahrungsschatz eines halben Jahrhunderts in der Produktion technischer Keramik, gewährleisten ein hohes Leistungs- und Qualitätsniveau. Leistung und Qualität zusammen sind es, die unsere Erzeugnisse auf der ganzen Welt zu einem festen Begriff werden ließen. Der Exportanteil von etwa einem Drittel veranschaulicht unsere Wettbewerbsfähigkeit.

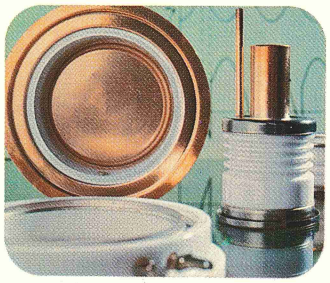


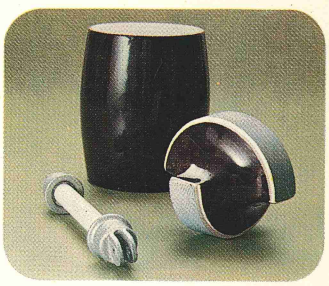






Rosenthal Technik AG, one of the world's largest group of companies producing technical ceramics, founded in 1971 by the merger of the technical ceramic factories of Rosenthal Isolatoren GmbH (RIG) at Selb, Rosenthal Technische Werke (RTW) at Marktredwitz and Steatit Magnesia (Stemag) at Lauf. Rosenthal Technik AG a affiliated company of Rosenthal AG, handle all activities in the field of technical ceramics within the Rosenthal group.





Rosenthal Technik AG offers a full range of technical ceramics covering nearly all materials applied in modern industry. The most modern techniques and our experience of half a century in the manufacture of technical ceramics guarantee a high level of efficiency and quality. Efficiency and quality have made our products famous throughout the world. An export share of one third of our production demonstrates our competitative ability.

can be attributed to the measuring-cable changes rather than to components. Solid dielectric cables were less affected by pulses than the composite air-plus-type cable.

Adams[110] presented data on the evaluation of insulated wires and cables under simulated space conditions (including the lunar environment). Reduction in weight and size is a primary target of this wire- and cable-development activity. In many applications, signal leads constitute the bulk of the hook-up wire used. AWG #32 copper wire is adequate, based on electrical requirements, but mechanical considerations dictate the use of AWG #24. New alloys of copper with zirconium and cadmium show promise of increasing the durability with little sacrifice in resistance. Another approach to the mechanical strength problem would be to fuse the wires into a monolithic structure as in present flat and contour cables. In general, TFE-insulated wire is best for all-around use in aerospace, but where outgassing or flammability are not problems, irradiated polyethylene could be used.

Klein and Scheiber[111] calculated the pressure differences for the insulation of an oil-filled pressure cable with fluted sheath, and the results were compared with those in a cable with a smooth sheath.

Erskine, Ricks, and Rudd[112] described the experience of the British Electricity Board with plastic-insulated cables for low-voltage distribution. Milne, Bates, and Gorham[113] reported on extensive trials the Electricity Board made on low- and medium-voltage, plastic-insulated-mains cables and on the limited trials with high-voltage, plastic-insulated-mains cables. Some of the methods used in the application of accessories were tried to simplify jointing procedure.

Stutz[114] discussed the replacement of cable-distribution-steel cabinets by reinforced-fiber-glass houses.

Neher[115] gave several families of curves, developed on a digital cumputer, which help determine the transient temperature rise of a buried-cable system.

V. Capacitors, Switchgear, and Insulators

Vail[116] reviewed the application requirements for dc filter and energy-storage capacitors.

Lengyel and Mitra[117] measured the electrical conductivity of thin, oil-impregnated, paper-insulated capacitors at high-electric fields as a function of temperature and voltage. They developed a theory which gave the approximate determination of the mobility of the charge carriers, assuming that the dominant part of the conduction in the oil takes place by means of ions.

Wehe and McMahon[118] described the development of a low-loss, polycarbonate-stripped-film capacitor. Its advantages are that it has low loss, approaching polystyrene, but is much smaller in size, and less sensitive to temperature, with an operating range between at least -78° and 125°C. The capacitors are "self-healing" and have long life under adverse conditions of temperature and voltage. An example of the size of one such hermetically sealed capacitor is .075 cubic inches in volume and 1/10 oz. in weight.

Johnston[119] related the experience of an explosion of flammable gases which occurred in August 1962 in a 161-kv oil circuit-breaker at the Oak Ridge gaseous-diffusion plant. He cites this as an example of flammable gases which might be produced by the decomposition of solid insulation and insulating oil as a result of faults in electrical equipment.

Kane and Colclaser[120] described a single-tank circuit-breaker, using SF_6 as the interrupting medium, and listed the test procedures used in life testing, voltage testing, and interruption testing.

Saffold[121] told of a new insulation system in which an improved high-strength electrical porcelain is the key ingredient for newly developed metal-clad switchgear.

Ketterer[122] described a commercial inorganic-bonded-mica paper for switchgear applications and listed some of its mechanical and electrical properties from room temperature to over 1000°C.

Tjebben[123] outlined a program for the environmental study of switchgear assemblies.

Woods[124] pointed out that cast epoxy insulation opens up complete new fields for switchgear and power-transformer design. He discussed the properties of resins as designed for application to busbars, bushings, and transformers. Dvoinikov[125] showed that an epoxy cement can be used to repair the porcelain casing of a 220-kv airblast circuit-breaker very effectively.

Yamamoto, Kawai, Kagaya, and Kojima[126] described the development of an elephant-type bushing in a cooperative undertaking by Japanese machine and cable manufacturers. This bushing incorporates a directly connected combination of high-voltage cable, pothead, and transformer.

Vose and Nichols[127,128] have developed suspension insulators using a modified epoxy-type polymer with a fiber-glass core. Development insulators of this type (to replace porcelain insulators) have been in outdoor service on transmission lines of 69 kv to 115 kv for about four years without service difficulty.

Observers have established that conventional suspension-type insulators indicate a statistical loss of strength with time, stabilizing at values above the normal, recommended working loads. Kaminski[129] feels that the principal cause of such depreciation is due to the deterioration of the material used as lubricants on metallic load-bearing surfaces, particularly on the lip of the cap. He described a means for evaluating the expected long-time-insulator strength by a thermal-load test.

Alston and Zoledziowski[130] analyzed the growth of discharges on polluted insulation. Their analysis is based on the insulator having a constant resistance, r_c, in ohms per centimeter of leakage length. They found that the flashover stress, E_c, is proportional to $r_c^{0.43}$ with the constant of proportionality dependent on the insulator material; but E_c is not less than $10.5\ r_c^{0.43}$ V (peak) per centimeter at power frequencies. E_c was also proportional to $\rho^{0.43}$ where ρ is the resistivity of the pollution; this was found to hold for conventional bushings subjected to the wet flashover test. The analysis also shows that the maximum current which can flow along the insulation when flashover is impossible is $233\ E_c^{-1.31}$ amps.

Dvoracek[131] found that maintenance costs of high-voltage insulators in contaminated atmospheres can be minimized by ample dimensioning and suitable shaping.

Reverey[132] made leakage-current measurements on insulators at a testing station over a period of years and concluded that no evaluation is possible from the observation of discharge currents unless they are extended over a period of many years.

Valeev and Esikov[133] measured the change in breakdown potential of insulators as a function of relative humidity and surface condition in a test chamber (between ambient and 45°C to humidities of 100 per cent). Their results generally agree with published values.

Nasser[134] tested 110-kv, one-piece, suspension-type rod insulators for flashover with artificial contamination distribution. Uniform distribution gives the lowest flashover voltages; if the layer is thicker on the insulator caps than below, the flashover voltage is 40 per cent higher; with higher conductivity and thinner-layer contaminants, only slightly higher flashover values are obtained.

Standring, Browning, Hughes, and Roberts[135] studied factors affecting 50-cps wet flashover tests, such as the angle at which water drops hit the insulator and the quantity of water striking the insulator. They presented the results of the effect of humidity on flashover of air gaps and insulators for ac (50 cps) and impulse (1/50 μ sec) voltages. They presented flashover data with 1/50 μ sec. impulses and preliminary work with switching surges for air gaps, string insulators, and post insulators for use in transmission systems at voltages from 132 to 400 kv.

Kalb[136,137] made full-scale, switching-surge flashover tests at an outdoor set-up that covered a range of V-string and vertical-insulator-string lengths, tower sizes and wave shapes. He explored the response of line insulation to these surges. He investigated the effects of precipitation and preceding trapped charges (bias voltage) and rod-to-ground and conductor-to-ground flashover. Estimated performance curves of EHV transmission-line structures indicate the economic justification for switching-surge-limiting apparatus.

Hill and Kinyon[138] conducted switching-surge flashover tests on various composite suspension-insulator assemblies. Emphasis is placed on conditions which produce flashover at lowest voltages, e.g., the positive switching-surge wet test. The wet-test procedure used simulated conditions in the Pacific Northwest.

Wagner, Clayton, Young, and Rudasill[139] reported on a detailed study of the Virginia Electric & Power Company's 500-kv transmission system to determine optimum insulation levels for substation equipment. Udo[140] gave the test results on the sparkover characteristics of large-gap spacings and long insulator strings. Impulse-sparkover characteristics for rod gaps have been extended up to a spacing of eight meters.

Tests made by Johnson, Wilson, Anderson, Lambert, Lice, and Turner[141], in which they use a mock-up tower structure to determine flashover levels of switching surge, impulse, and 60-cycle voltages for use in designing a 500-kv line, are described.

LaForest, Lindh, MacCarthy, Olsen, and Schulz[142] logged fair- and foul-weather corona-loss and radio-noise data continuously from three configurations tested at 500 kv and another at 700 kv. The data were analyzed by computer. Morris and Rakoshdas[143] measured corona loss and radio interference from a single "Drake" conductor and a two-conductor "Drake" installed on two short test lines using dc up to 600 kv positive and negative under a variety of weather conditions and voltage levels.

Graybill[144] described the application of high-strength alumina-porcelain insulators to outdoor air switches in some detail. Terry[145] reviewed the electrical properties of various ceramics and some of the processing factors which influence the electrical properties.

VI. Other Applications

Colby and Ursch[146] discussed the application of epoxy resins to high-voltage components in the electronics industry. Bramley and Dorn[147] reviewed methods of epoxy encapsulation and the mechanical equipment developed in the past few years for applying epoxies in the electronics industry. They discussed the fluidized-bed process, the flock gun and the electrostatic-spray gun. Koved[148] described the design factors to be considered in the selection of resins and the tests and environmental factors to be considered in encapsulating as per MIL specs, particularly for transformers.

Uglione and Bell[149] evaluated polyurethanes, polysulfides, and epoxies for connector potting and molding applications. They found that only the polyurethanes are suitable for both potting and molding applications.

The major areas of application of plastics in microwave electronic devices are as insulation, adhesives, and encapsulation. Steinhardt[150] discussed the use of Ferrite isolators, silicone-rubber sealants, and insulation against RF arc-over; the use of RTV silicone rubber and flexible epoxies as adhesives and encapsulation with a thixotropic epoxy for these applications.

The nature of irradiated polyolefins and their application for encapsulating capacitors, resistors, miniature circuit boards, and wire junctions are the subjects of a paper by Sherlock[151]. In an anonymous article[152], the application of heat-shrinkable, reinforced-plastic sleeving for harnesses, cables, connections, and the encapsulation of components is described.

Lanza and Stivers[153] gave the results of tests in developing a new polyolefin for space use.

Shane[154] described the method used to evaluate thirty different materials for conformal anti-humidity coatings. He used three different printed wiring-board substrates on which the materials are coated and, by evaluating five different factors, arrived at a merit rating. In general, the best results are obtained on glass-epoxy boards followed by XXXP phenolic, with coatings on a paper-reinforced epoxy laminate showing the poorest results.

Beccasio[155] etched various paper-phenolic, paper-epoxy and glass-epoxy laminates with epoxy, polyurethane, silicone or MIL-V-173-type coatings on comb and two parallel-line test patterns. He tested various thicknesses of coatings by several mechanical and electrical parameters; they all met MIL-P-13949. He also investigated chemical and mechanical methods for removing coatings from printed wire assemblies, recoating, and testing. This was to determine suitable repair procedures.

Learn[156] described tests which led to the decision to use polyester powders as the integral ground insulation and protective coating on motors.

Feuchtbaum[157] discussed methods to accomplish repairable encapsulation of modules.

Hanson and Heaton[158] described the evolution of automatic electronic production with pressure-sensitive adhesive tapes from simple hand operations to completely automatic tape-dispensing machines. He gave examples of manual semi-automatic and fully automatic tape-dispensing machinery.

Traut and Anderson[159] outlined methods for making flexible circuitry by mechanical methods (die blanking and die stamping) and reviewed the present status in the development of synthetic fiber paper for insulating such circuits. Day[160] gave a step-by-step procedure for the processing of printed circuit boards in a small business or laboratory; he described the selection of materials and how to use them for this application. Barron[161] described specially designed machines and tools for sawing, slitting, and matching of copper-clad etched circuit boards.

Saunders[162] reviewed the various materials needed for application in electrical apparatus to be used at high temperatures (250° to 650°C), particularly using ceramics.

VII. Evaluation of Insulating Materials

The AIEE 510 Working Group[163] reviewed the progress they made in the last three years. They included an outline of the studies and decisions reached regarding such items as test unit assembly, test temperature cycles, humidity conditioning, and failure detection in motorettes.

Hi-Lite

SUSPENSION INSULATORS

Hi*Lite published mechanical values inaugurate a new system of strength ratings stated as MAXIMUM DESIGN TENSION. The insulator may be worked at any mechanical load up to the maximum design tension shown below and on the nameplate.

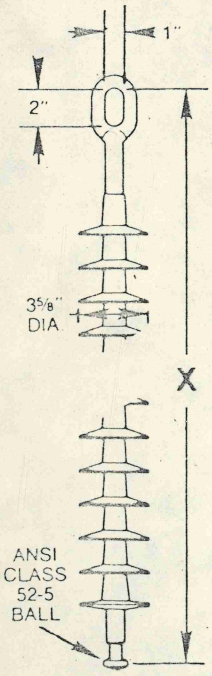


Figure 1
10,000 Lbs.
Maximum
Design
Tension

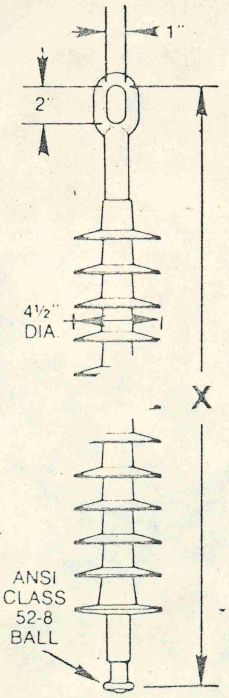


Figure 2
20,000 Lbs.
Maximum
Design
Tension

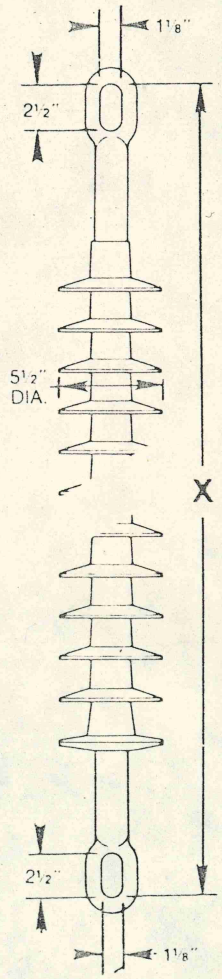


Figure 3
40,000 Lbs.
Maximum
Design
Tension

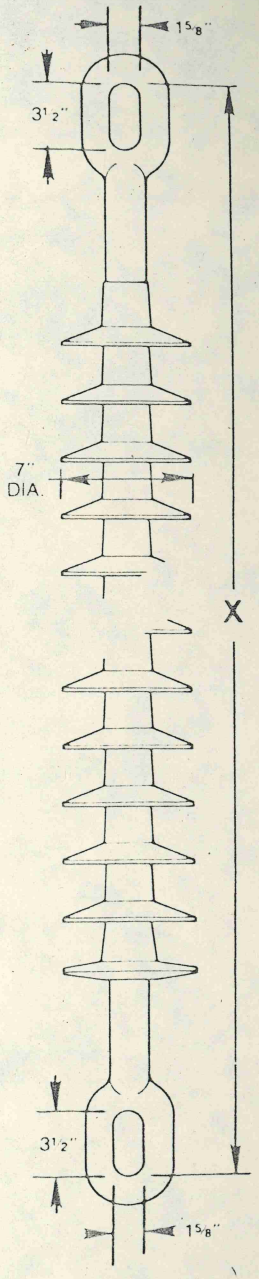


Figure 4
80,000 Lbs.
Maximum
Design
Tension

ROD DIA 5/8 7/8 1 1/4 1 3/4

NOTE: In Figures 1 and 2, an eye similar to top connection may be substituted for the ball when specified.

MAX DESIGN TENSION ≅ 1/3 UTS OF COMPLETE ASSEMBLY

	Catalog Number	Section** Length X	Leakage Distance	Dry Arcing Distance	60-Hz Flashover		Impulse Critical		Net Weight**
					Dry	Wet	Positive	Negative	
		in.	in.	in.	kv	kv	kv	kv	lbs.
Figure 1 ‡10,000 Lbs. Maximum Design Tension	232008	37⅞	75	31¾	325	265	540	520	7
	232009	43⅝	90	37½	380	315	620	600	8½
	232010	51⅝	112	45½	450	380	740	730	9½
	232011	63⅝	145	57½	560	475	920	920	11½
	232012	83⅝	200	77½	730	635	1225	1250	15
	232013	93⅝	222	87½	820	710	1370	1400	17
	232014	103⅝	250	97½	900	780	1520	1550	19
	232015	123⅝	300	117½	1050	925	1820	1850	22½
Figure 2 ‡20,000 Lbs. Maximum Design Tension	232019	44⅛	92	35¾	370	300	590	575	11½
	232020	52⅛	114	43¾	430	365	710	690	13½
	232021	64⅛	146	55¾	540	460	885	890	16½
	232022	84⅛	202	75¾	725	625	1190	1200	21¼
	232023	94⅛	232	85¾	800	695	1340	1360	24
	232024	104⅛	258	95¾	880	770	1490	1515	26¼
	232025	124⅛	314	115¾	1030	910	1790	1815	31¼
	232026	144⅛	370	135¾	1200*	1040*	2090	2100	36¼
	232027	164⅛	430	155¾	1330*	1205*	2350*	2370*	41
	232028	226⅛	600	217¾	1600*	1460*	3100*	3100*	56¼
Figure 3 ‡40,000 Lbs. Maximum Design Tension	232032	87	190	73	710	600	1150	1180	34½
	232034	107	254	93	860	750	1450	1480	42
	232035	127	305	113	1010	890	1750	1780	46½
	232036	147	365	133	1200*	1025*	2050	2070	56
	232037	167	425	153	1320*	1140*	2320*	2330*	63
	232038	229	600	215	1580*	1460*	3000*	3000*	85
	232039	247	635	233	1680*	1525*	3200*	3200*	91½
Figure 4 ‡80,000 Lbs. Maximum Design Tension	232042	90	180	69½	675	570	1100	1025	61½
	232044	110	240	89½	875	725	1400	1430	72
	232045	130	290	109½	990	865	1700	1720	84
	232046	150	340	129½	1160*	1000*	2000	2000	96
	232047	170	400	149½	1300*	1120*	2250*	2250*	107
	232048	232	580	211½	1560*	1450*	3000*	3000*	145
	232049	250	630	229½	1650*	1515*	3200*	3200*	151

‡**MAXIMUM DESIGN TENSION** is the maximum mechanical load the insulator is designed to carry.

*Extrapolated value. For long strings the actual test values will vary, depending on ground plane effects. Full scale tests are recommended before writing final specifications.

**In Figures 1 and 2, if eye is substituted for ball at lower end, add 1¼ inch length and ½ pound weight to Figure 1, or 1½ inch length and 1 pound weight to Figure 2.

OHIO B

HI-LITE SUSPENSION INSULATORS

Cat No	Workg Load	Sect Lgth	Net Price
232008	10 K	37	$ 46.
009	10	43	54.
010	10	51	64.
011	10	63	79.
232012	10	83	$ 104.
013	10	93	116.
014	10	103	129.
015	10	123	154.
232019	20 K	43	$ 108
020	20	51	128.
021	20	63	158.
022	20	83	208.
023	20	93	233.
232024	20	103	$ 258.
025	20	123	308.
026	20	143	358.
027	20	163	408.
028	20	225	563.
232032	40 K	86	$ 502.
034	40	106	618.
035	40	126	735.
036	40	146	852.
232037	40	166	$ 968.
038	40	228	1330.
039	40	246	1435.
232042	80 K	88	$1173.
044	80	108	1440.
045	80	128	1707.
046	80	148	1973.
232047	80	168	2240.
048	80	230	3067.
049	80	248	3307.

Work Load = Maximum design tension = Maximum mechanical load are designed for under any conditions = 1/10 of breaking strength of fiberglass rod only = 1/3 of estimated bending strength of insulator assembly.

Polymer insulators loose some strength with load & time

HI-LITE HORIZONTAL POST INSULATORS

Cat No	Workg Load Cantilever	Distance to Pole Face	Net Price
232101	2000 lb	40 in	$145.00
102	1650	46-3/8	185.00
103	1400	52-1/2	195.00
104	1100	65-1/2	220.00
232105	2000 lb	41-1/8 in	$145.00
106	1650	47-1/2	185.00
107	1400	53-5/8	195.00
108	1100	66-5/8	220.00

Howard G. Kensel
5-1-76

Service Instrument Corp., Cockeysville, MD
Skarshaug Testing Laboratory, Ames, IA
Sunshine Scientific Instruments, Philadelphia, PA
Taplin, D. E. Power Equipment, Parramatta (Sydney), N.S.W. Australia
Universal Voltronics Corp., Mt. Kisco, NY
Western Electro-Mechanical Co., Inc., Oakland, CA
Western Progress, Inc., Mountain View, CA

INDICATORS, PORTABLE—LOAD

Adelphon, Inc., Arlington, TX
American Hoist & Derrick Company, St. Paul, MN
Biddle, James G. Co., Plymouth Meeting, PA
Canadian Research Institute, Don Mills, Ontario, Canada
Chance, A. B. Co., Utility Systems Div., Subs. of Emerson Electric Co., Centralia, MO
Dranetz Engineering Laboratories Inc., South Plainfield, NJ
E.I.L. Instruments, Inc., Timonium, MD
General Electric Company, Schenectady, NY
Graybar Electric Co., Inc., New York, NY
Sunshine Scientific Instruments, Philadelphia, PA
Universal Voltronics Corp., Mt. Kisco, NY

INDICATORS, PORTABLE—PHASE SEQUENCE

Amprobe Instrument, Lynbrook, NY
Associated Research Inc., Chicago, IL
Avtron Manufacturing Inc., Cleveland, OH
Biddle, James G. Co., Plymouth Meeting, PA
Canadian Research Institute, Don Mills, Ontario, Canada
Chance, A. B. Co., Utility Systems Div., Subs. of Emerson Electric Co., Centralia, MO
Commonwealth Engineering & Sales, Montreal H4L 4V7 Canada
Devco Engineering Inc., Fairfield, NJ
Dranetz Engineering Laboratories Inc., South Plainfield, NJ
E.I.L. Instruments, Inc., Timonium, MD
Eastern Specialty Co., The, Philadelphia, PA
Electrical Testing Instruments Ltd., Ontario, Canada
EPIC Inc., New York, NY
Ferguson, Brosz & Associates Limited, Scarborough, Ontario, Canada M1P 2Y7
Gould Inc., Rolling Meadows, IL
Graybar Electric Co., Inc., New York, NY
Hill Research Co., Oakland, CA
Knopp Inc., Oakland, CA
Meter Devices Company, Canton, OH
Micro Instrument Co., Escondido, CA
Opad Electric Co., Inc., New York, NY
Ross Engineering Corp., Campbell, CA
Safety Line, Inc., Oakland, CA
Service Instrument Corp., Cockeysville, MD
Sticht, Herman H. Co., Inc., New York, NY
Sunshine Scientific Instruments, Philadelphia, PA
Taplin, D. E. Power Equipment, Parramatta (Sydney), N.S.W. Australia
Time Mark Corporation, Tulsa, OK
Western Electro-Mechanical Co., Inc., Oakland, CA

INDICATORS, PORTABLE—TEMPERATURE

Acco, Bridgeport, CT
Amprobe Instrument, Lynbrook, NY
Bailey Meter Co. Sub. of Babcock & Wilcox Co., Wickliffe, OH
Barnes Engineering Co., Stamford, CT
Biddle, James G. Co., Plymouth Meeting, PA
Canadian Research Institute, Don Mills, Ontario, Canada
Chance, A. B. Co., Utility Systems Div., Subs. of Emerson Electric Co., Centralia, MO
Doric Scientific Corp., San Diego, CA
E.I.L. Instruments, Inc., Timonium, MD
EPIC Inc., New York, NY
General Electric Company, Schenectady, NY
Graybar Electric Co., Inc., New York, NY
H-B Instrument Company, Philadelphia, PA
Leeds & Northrup Company, North Wales, PA
Mag-Con Inc., St. Paul, MN
Mikron Instrument Co., Inc., Ridgewood, NJ
Muirhead-Addison, Inc., Mountainside, NJ
Raytek, Inc., Mountain View, CA
RdF Corporation, Hudson, NH
RFL Industries, Inc., Boonton, NJ
Sagline Inc., Millwood, NY
Sperry, A. W., Instruments Inc., Hauppauge, NY
Sunshine Scientific Instruments, Philadelphia, PA
Taplin, D. E. Power Equipment, Parramatta (Sydney), N.S.W. Australia
Triplett Corporation, Bluffton, OH
Weston Instruments, Inc., Newark, NJ
Williamson Corp., Concord, MA

INFLATORS—GLOVE

Biddle, James G. Co., Plymouth Meeting, PA
Graybar Electric Co., Inc., New York, NY
Skarshaug Testing Laboratory, Ames, IA
White Rubber Co., The, Ravenna, OH

INSPECTION SERVICES—AERIAL LINE PATROL

Allied Helicopter Service, Inc., Tulsa, OK
Asplundh Aviation Inc., Willow Grove, PA
Asplundh Tree Expert Co., Jenkintown, PA
Campbell Air Service, Inc., Vivian, LA
Evergreen Helicopters of Alaska, Inc., Anchorage, AK
Helicopter Minit-Men, Inc., Columbus, OH
Keystone Helicopter Corp., West Chester, PA
Petroleum Helicopters, Inc., Lafayette, LA

INSPECTION SERVICES—CROSSARMS

Adams Engineering, Inc., Minneapolis, MN
Commonwealth Associates Inc., Jackson, MI
Pole Sprayers, Inc., Buffalo, NY
Williams, A. W., Inspection Co., Inc., Mobile, AL

INSPECTION SERVICES—INFRARED (POWER SYSTEMS)

AGA Corporation, Secaucus, NJ
Asplundh Aviation Inc., Willow Grove, PA
Asplundh Tree Expert Co., Jenkintown, PA
Barnes Engineering Co., Stamford, CT
Davey Tree Expert Company, The, Kent, OH
Ferguson, Brosz & Associates Limited, Scarborough, Ontario, Canada M1P 2Y7
General Electric Co. - Apparatus Service Div., Schenectady, NY
Geophysical Survey Systems, Inc., Burlington, MA
Helicopter Minit-Men, Inc., Columbus, OH
Infrared Surveys Inc., Houston, TX
Raytek, Inc., Mountain View, CA
Transformer Consultants, Div., S. D. Myers, Inc., Akron, OH

INSPECTION SERVICES—INVENTORY, OUTSIDE PLANT

Beck, R. W. and Associates, Seattle, WA
Commonwealth Associates Inc., Jackson, MI
Construction Materials Testing Institute, North Wales, PA
Henkels & McCoy, Inc., Blue Bell, PA
Miner and Miner, Consulting Engineers, Inc., Greeley, CO
Stanley Consultants, Inc., Muscatine, IA
Telcom Engineering Inc., St. Louis Air Park, MO
Utilities Service-Division of Heath International, Inc., Richmond, MI
Vernon Graphics, Inc., Elmsford, NY

INSPECTION SERVICES—POLES

Adams Engineering, Inc., Minneapolis, MN
Asplundh Tree Expert Co., Jenkintown, PA
Commonwealth Associates Inc., Jackson, MI
Geophysical Survey Systems, Inc., Burlington, MA
Henkels & McCoy, Inc., Blue Bell, PA
Osmose Wood Preserving Co. of America, Inc., Buffalo, NY
Pole Sprayers, Inc., Buffalo, NY
Utilities Service-Division of Heath International, Inc., Richmond, MI
Williams, A. W., Inspection Co., Inc., Mobile, AL

INSULATION—RAW MATERIAL

Babcock & Wilcox Co. Refractories Div., Augusta, GA
Dow Corning Corporation, Midland, MI
DuPont de Nemours E. I. & Co. - Elastomer Chemicals Dept., Wilmington, DE
DuPont Electrical Elastomers, Wilmington, DE
Formed Plastics, Inc., Carle Place, L.I., NY
G E T Plastics, Inc., St. Louis, MO
General Electric Co., Insulating Materials Dept., Schenectady, NY
General Electric Co., Silicone Products Dept., Waterford, NY
General Gasket Corp., St. Louis, MO
Hardman Incorporated, Belleville, NJ
Johns-Manville Corp., Denver, CO
Keene Corporation Chase-Foster Division, East Providence, RI
Masonite Corporation, Chicago, IL
Owens Corning Fiberglas Corp., Toledo, OH
Royal Industries, Tetrafluor Division, El Segundo, CA
Schlatter, H.A., Inc., Rockford, IL
Tapecoat Co., The, Evanston, IL
Zippertubing Co., The, Los Angeles, CA

INSULATORS—PIN TYPE

Anixter-Pruzan, Inc., Seattle, WA
Chance, A. B., Co., Utility Systems Div., Subs. of Emerson Electric Co., Centralia, MO
Gould Inc., Rolling Meadows, IL
Graybar Electric Co., Inc., New York, NY
Hendrix Wire & Cable Corp., Milford, NH
Hubbard and Company, Emeryville, CA
Joslyn Mfg. & Supply Co., Chicago, IL
Joslyn Mfg. and Supply Co. - Pinco Div., Lima, NY
Knox Porcelain Corporation, Knoxville, TN
McGraw-Edison Power Systems Division, Canonsburg, PA
Moritani America, Inc., Chicago, IL
NGK-Locke, Inc., New York, NY
Ohio Brass Company, The, Mansfield, OH
Patterson Electric Co., Inc., Ligonier, PA
Porcelain Products Company, Carey, OH
Porter, H. K., Company, Inc., Electrical Division, Pittsburgh, PA
Synthetic Products Mfg. Corp., Sub. Reliable Electric Co., Leominster, MA

INSULATORS—POLYMER

Anixter-Pruzan, Inc., Seattle, WA
Barron Bethea Company, Inc., Birmingham, AL
Chance, A. B., Co., Utility Systems Div., Subs. of Emerson Electric Co., Centralia, MO
G E T Plastics, Inc., St. Louis, MO
Graybar Electric Co., Inc., New York, NY
Haveg Industries Inc., Sub. of Hercules Inc., Reinhold Aerospace Div., Santa Fe Springs, CA
Haveg Industries, Inc. - Industrial & Aerospace Div. - Sub. of Hercules, Inc., Taunton, MA
Hendrix Wire & Cable Corp., Milford, NH
Ohio Brass Company, The, Mansfield, OH
Osborne Electric Co. Ltd., Toronto, Ontario M8Z 5M4, Canada
Patterson Electric Co., Inc., Ligonier, PA
Permali, Inc., Mount Pleasant, PA
Permali, Inc. - Transmission Developments Div., Mt. Pleasant, PA
Rebosio, R.I.E. - Milano (Italy), New York, NY
Reliable Electric, Franklin Park, IL
Rosenthal Technik Werkqruppe I, West Germany
Royal Industries, Tetrafluor Division, El Segundo, CA
Shakespeare Industrial Products Division, Columbia, SC
Synthetic Products Mfg. Corp., Sub. Reliable Electric Co., Leominster, MA

INSULATORS—RUBBER

Anixter-Pruzan, Inc., Seattle, WA
Graybar Electric Co., Inc., New York, NY
Rosenthal Technik Werkqruppe I, West Germany
Skarshaug Testing Laboratory, Ames, IA

INSULATORS—SPOOL

Anixter-Pruzan, Inc., Seattle, WA
Chance, A. B., Co., Utility Systems Div., Subs. of Emerson Electric Co., Centralia, MO
Dixie Electrical Mfg. Company, Birmingham, AL
Gould Inc., Rolling Meadows, IL
Graybar Electric Co., Inc., New York, NY
Hubbard and Company, Emeryville, CA
Joslyn Mfg. & Supply Co., Chicago, IL
Knox Porcelain Corporation, Knoxville, TN
Moritani America, Inc., Chicago, IL
NGK-Locke, Inc., New York, NY
Ohio Brass Company, The, Mansfield, OH
Oliver Division of Sangamo Electric Company, Vicksburg, MS
Patterson Electric Co., Inc., Ligonier, PA
Porcelain Products Company, Carey, OH
Porter, H. K., Company, Inc., Electrical Division, Pittsburgh, PA
Utilities Service Co., Allentown, PA
Weaver, J. A., Co., St. Louis, MO

INSULATORS—STRAIN

Anixter-Pruzan, Inc., Seattle, WA
Barron Bethea Company, Inc., Birmingham, AL
Chance, A. B., Co., Utility Systems Div., Subs. of Emerson Electric Co., Centralia, MO
Gould Inc., Rolling Meadows, IL
Graybar Electric Co., Inc., New York, NY
Hughes Brothers, Inc., Seward, NB
Joslyn Mfg. & Supply Co., Chicago, IL
Kearney, Atlanta, GA
Knox Porcelain Corporation, Knoxville, TN
Lapp Insulator Division, Interpace Corp., Le Roy, NY
Locke Insultors, Inc., Baltimore, MD
Moritani America, Inc., Chicago, IL
NGK-Locke, Inc., New York, NY
Ohio Brass Company, The, Mansfield, OH
Oliver Division of Sangamo Electric Company, Vicksburg, MS
Patterson Electric Co., Inc., Ligonier, PA
Permali, Inc. - Transmission Developments Div., Mt. Pleasant, PA
Porcelain Products Company, Carey, OH
Porter, H. K., Company, Inc., Electrical Division, Pittsburgh, PA
Reliable Electric, Franklin Park, IL
Rosenthal Technik Werkqruppe I, West Germany
Shakespeare Industrial Products Division, Columbia, SC
Square D Company, Park Ridge, IL
Weaver, J. A., Co., St. Louis, MO

INSULATORS—SUSPENSION

Anixter-Pruzan, Inc., Seattle, WA
Chance, A. B., Co., Utility Systems Div., Subs. of Emerson Electric Co., Centralia, MO
Gould Inc., Rolling Meadows, IL
Graybar Electric Co., Inc., New York, NY
Joslyn Mfg. & Supply Co., Chicago, IL
Joslyn Mfg. and Supply Co. - Pinco Div., Lima, NY
Knox Porcelain Corporation, Knoxville, TN
Lapp Insulator Division, Interpace Corp., Le Roy, NY
Locke Insultors, Inc., Baltimore, MD
Moritani America, Inc., Chicago, IL
NGK-Locke, Inc., New York, NY
Ohio Brass Company, The, Mansfield, OH
Patterson Electric Co., Inc., Ligonier, PA
Permali, Inc., Mount Pleasant, PA
Permali, Inc. - Transmission Developments Div., Mt. Pleasant, PA
Porcelain Products Company, Carey, OH
Porter, H. K., Company, Inc., Electrical Division, Pittsburgh, PA
Rosenthal Technik Werkqruppe I, West Germany
Sediver, Inc., Carlstadt, NJ

INSULATORS—SWITCH AND BUS

Anixter-Pruzan, Inc., Seattle, WA
Chance, A. B., Co., Utility Systems Div., Subs. of Emerson Electric Co., Centralia, MO
Diamonite Products Division, Shreve, OH
Electrical Manufacturing Co. Ltd., Montmagny, Quebec, Canada
Glastic Corp., Cleveland, OH
Gould Inc., Rolling Meadows, IL
Graybar Electric Co., Inc., New York, NY
Joslyn Mfg. & Supply Co., Chicago, IL
Joslyn Mfg. and Supply Co. - Pinco Div., Lima, NY
Lapp Insulator Division, Interpace Corp., Le Roy, NY
Locke Insultors, Inc., Baltimore, MD
Montel Inc., Montmagny, Quebec, Canada
Moritani America, Inc., Chicago, IL
NGK-Locke, Inc., New York, NY
Ohio Brass Company, The, Mansfield, OH
Patterson Electric Co., Inc., Ligonier, PA
Permali, Inc. - Transmission Developments Div., Mt. Pleasant, PA
Porcelain Products Company, Carey, OH
Porter, H. K., Company, Inc., Electrical Division, Pittsburgh, PA
Rosenthal Technik Werkqruppe I, West Germany
Southern Porcelain, Inc., Marietta, GA
Structural Substations Inc., Gresham, OR
Western Power Products, Inc., Hood River, OR
Westinghouse Electric Corporation, Pittsburgh, PA

INSULATORS, GUY STRAIN—FIBER GLASS REINFORCED

Anderson Electrical Connectors, Square D Co., Leeds, AL
Anixter-Pruzan, Inc., Seattle, WA
Barron Bethea Company, Inc., Birmingham, AL
Continental Electric Co., Birmingham, AL
Dixie Electrical Mfg. Company, Birmingham, AL
Graybar Electric Co., Inc., New York, NY
Joslyn Mfg. & Supply Co., Chicago, IL
Kearney, Atlanta, GA
Patterson Electric Co., Inc., Ligonier, PA
Permali, Inc. - Transmission Developments Div., Mt. Pleasant, PA
Plastigage Corporation, Jackson, MI
Rebosio, R.I.E. - Milano (Italy), New York, NY
Rosenthal Technik Werkqruppe I, West Germany

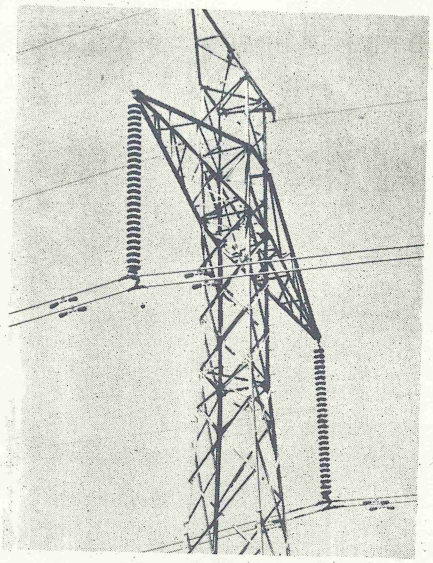
Test Proves Silicone Okay For HVDC Insulators

The Los Angeles Department of Water and Power has been testing a silicone compound on its HVDC transmission line. The tower for the test is about one mile from the Sylmar Converter Station and part of the 845-mile-long Pacific Intertie HVDC transmission line.

Although Sylmar is not considered an area of heavy contamination the insulators of the HVDC line collect particles and become dirty faster than the insulators on the comparable ac transmission lines. The particulate problem is aggravated by fog or nightly moisture condensation which makes the pollutant-soluble particles conductive and allows a leakage current over the insulator strings.

It is believed that some of the particulates are organic pollutants from vehicle exhausts on nearby freeways and that smog carries other pollutants from industrial facilities that are up to 60 miles away.

The Department tests were to determine the approximate length of time that the compound could be expected to prevent insulator flashover.



A 60-day insulator wash schedule is used on this tower in the 15-mile section of HVDC transmission line in Sylmar. Los Angeles Department of Water and Power selected the tower for long-term tests of silicone-coated insulator strings.

Dow Corning 3099 high voltage insulator compound was hand-applied in a nominal ⅛- to ¼-inch thickness on glazed porcelain suspension insulators in each of two strings.

After a 3-year test period, the high voltage silicone insulator compound had successfully protected the HVDC insulators from flashover. The compound was still hydrophobic, i.e., water would still bead up on its surface, but the compound had developed on the top side of the insulators a firm surface layer which no longer encapsulated atmospheric particles.

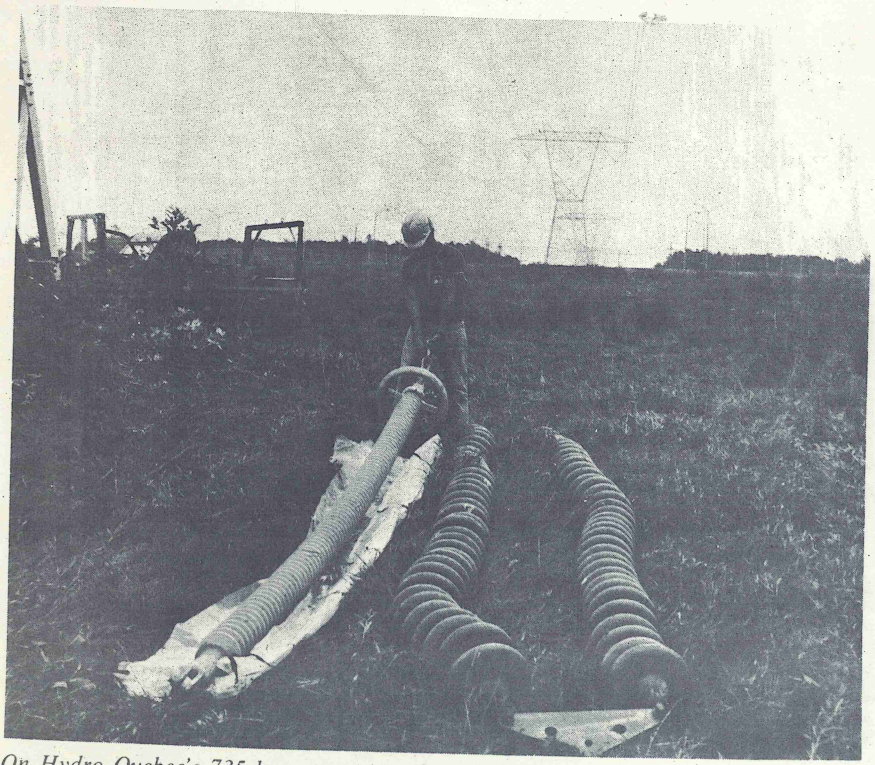
A major factor still to be determined is the difference in cost between washing the insulator strings every 60 days and the cost of applying the silicone compound to each of the strings.

Synthetic Insulators Used on 735-kv Line

Hydro-Quebec recently installed 240 synthetic insulators on 40 of the towers on the 735-kv transmission line between Laurentides and Levis substations, near Quebec City.

Using these new insulators on a transmission line exposed to severe weather marks the final phase of a test program undertaken in 1973. In the coming year, the utility expects to verify advantages of the new insulators ascertained in the laboratory.

The synthetic insulator is made of a fiber-glass rod encased in polymer to form a single unit. The synthetic insulators are said to weigh less than porcelain insulators and possess superior mechanical and electrical characteristics. For example, the equivalent synthetic insulation for two strings of conventional insulators weighing 548 kilograms is a single unit weighing only 32 kilograms. The new insulators also provide equal mechanical strength and cost less. A single unit of synthetic insulators has a diameter of only 13 centimeters, compared with 30 centimeters for each string of insulators.



On Hydro-Quebec's 735-kv transmission lines a single element synthetic insulator weighing only 32 kilograms may replace two-string porcelain insulators (right) weighing 548 kilograms.

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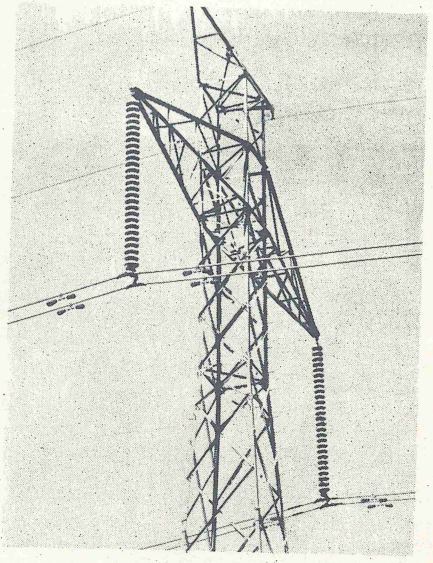

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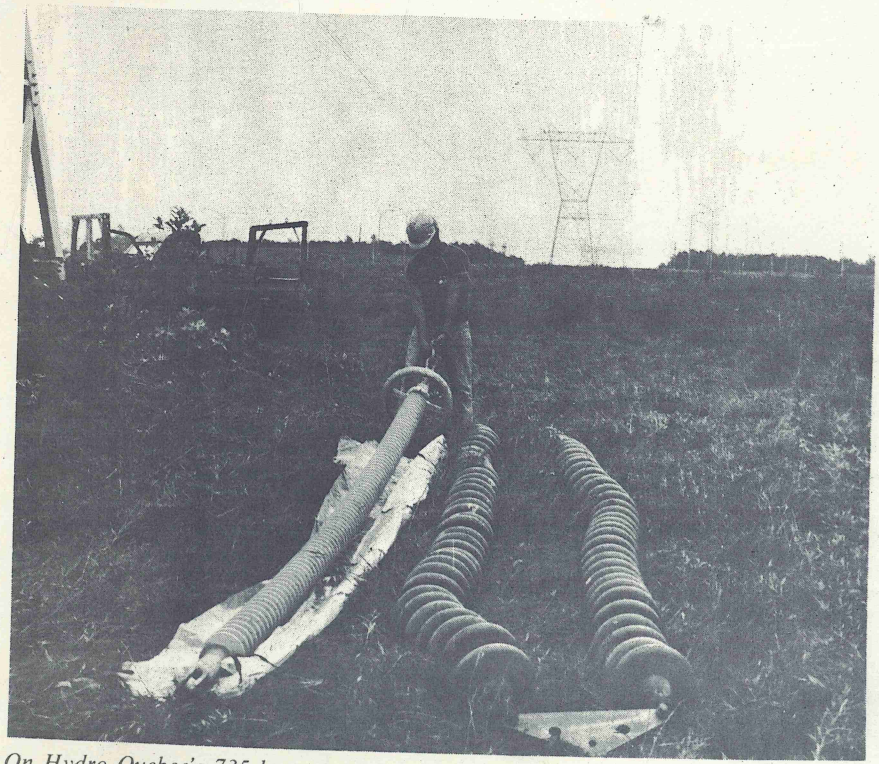

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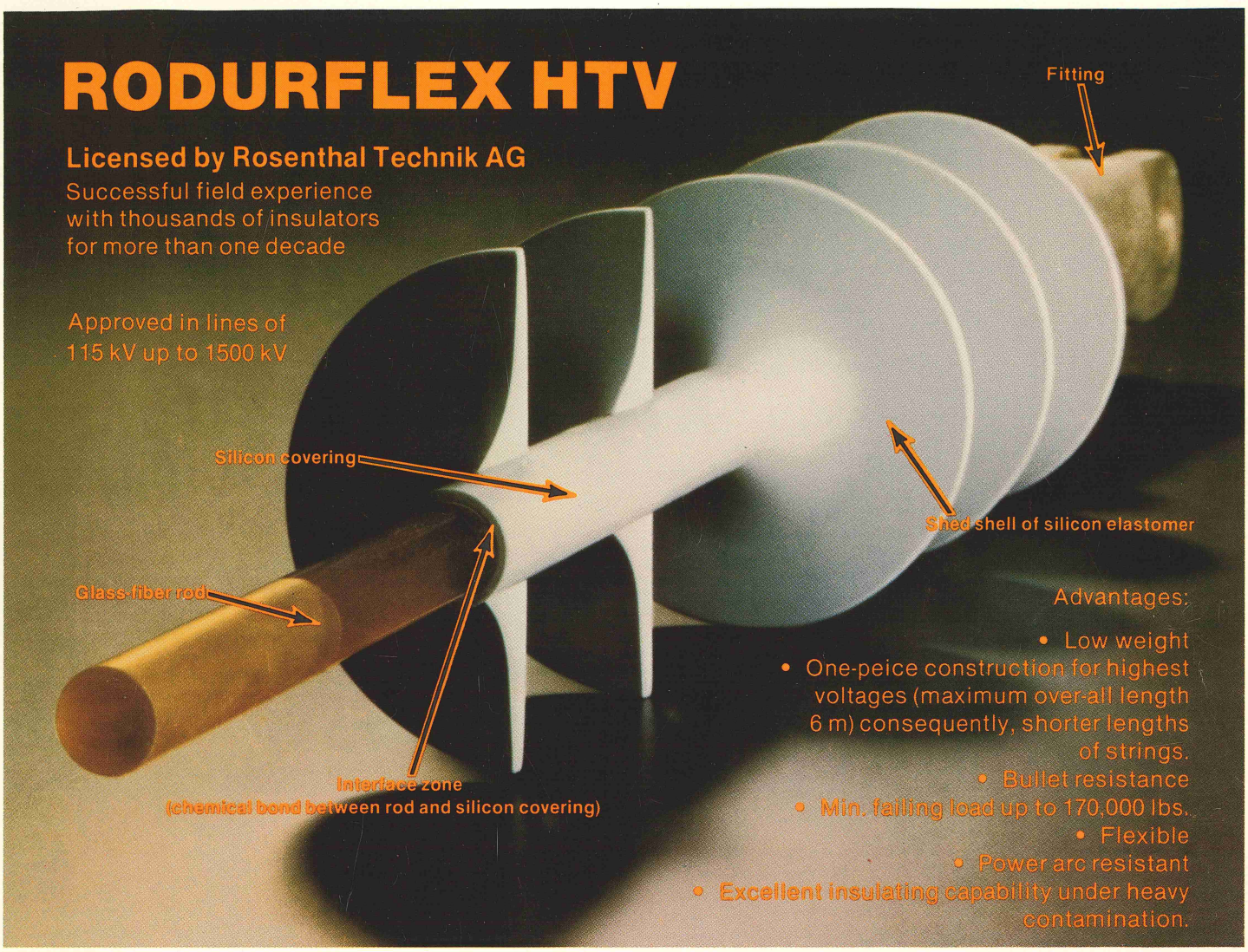
Composite Longrod Insulator according to the System



Construction of the RODURFLEX insulator

The primary member of these composite insulators consists of a mechanically and electrically high - strength glass fiber rod. Millions of glass fibers run through the rod from end to end and are embedded in epoxy resin without voids or cracks. The sheds consist of a high elastic silicone elastomer, the properties of which are nearly independent of the effects of high & low temperatures. The production method used enables great freedom with regard to the adaptation of the over-all length, shed overhang and shed spacing to the corresponding application case. In order to control, for a longer time, the unfavorable electrical longitudinal field stress in the interface, a chemical material boundary is necessary. Therefore, we selected a solution where the interface between the covering material and the rod consists of a thin active intermediate layer which is chemically bonded onto the rod. The prefabricated shed shell is then bonded on the covering. The high longitudinal puncture strength is not appreciably reduced by thermal and mechanical elongations of rod and sheds or by water vapor penetration. High strength end fittings are attainable by use of a special cleaving wedge connection. This end connection, which is force locking as well as form locking, meets all static and dynamic demands of the service rating of the insulator.

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